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PROCEEDINGS OF THE



NASA Earth Resources Survey Symposium

HOUSTON, TEXAS
JUNE 1975

FIRST COMPREHENSIVE SYMPOSIUM ON THE PRACTICAL APPLICATION OF EARTH RESOURCES SURVEY DATA

VOLUME I-C

TECHNICAL SESSION PRESENTATIONS

LAND USE – MARINE RESOURCES



National Aeronautics and Space Administration
LYNDON B. JOHNSON SPACE CENTER

NASA TM X-58168

NASA ERS Earth Resources Survey Symposium

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Land Use
Marine Resources

PREFACE

The first comprehensive symposium on the practical application of Earth resources survey data was sponsored by the NASA Headquarters Office of Applications from June 9 to 12, 1975, in Houston, Texas. The Lyndon B. Johnson Space Center acted as host.

This symposium combined the utilization and results of data from NASA programs involving LANDSAT, the Skylab Earth resources experiment package, and aircraft, as well as from other data acquisition programs.

The primary emphasis was on the practical applications of Earth resources survey technology of interest to a large number of potential users. Also featured were scientific and technological exploration and research investigations with potential promising applications.

The opening day plenary session was devoted to papers of general interest and an overview. The following 2-1/2 days were devoted to concurrent discipline-oriented technical sessions and to three special sessions covering State and Local Users, Coastal Zone Management, and User Services. These special sessions were structured to provide governmental and private organizations with a comprehensive picture of various applications in the management and implementation of remote-sensing data use in their own programs. The concluding day was a summary with selected state, international, and technical session papers, summaries of significant results from special and technical sessions, and an overview of federal agency and international activities and planning.

Volumes I-A, I-B, I-C, and I-D contain the technical papers presented during the concurrent sessions. Volume II contains the opening day plenary session, special sessions, and the concluding day summary session. Volume III contains a summary of each session by the chairman and session personnel and provides an overview of the significant applications that have been developed from the use of remote-sensing data. Volume III also includes the conclusions and needs identified during the individual sessions and workshops.

Opinions and recommendations expressed in these reports are those of the session members and do not necessarily reflect the official position of NASA.

Olav Smistad
Symposium Coordinator

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THE SOUTH DAKOTA COOPERATIVE LAND USE EFFORT: A STATE LEVEL REMOTE SENSING DEMONSTRATION PROJECT

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ABSTRACT

Remote sensing technology can satisfy or make significant contributions toward satisfying many of the information needs of governmental natural resource planners and policy makers. Recognizing this potential, the South Dakota State Planning Bureau and the EROS Data Center together formulated the framework for an ongoing Land Use and Natural Resource Inventory and Information System Program. Statewide land use/land cover information is currently being generated from LANDSAT digital data and high altitude photography. Many applications of the system are anticipated as it evolves and data is added from more conventional sources. This paper primarily deals with the conceptualization, design, and implementation of the program.

INTRODUCTION

All levels of government share the need for natural resource information. Intelligent planning, policy formulation, and decision making often require a great deal of qualitative and quantitative information. Without a solid information base, the planning process can be reduced to guesswork, a regrettable situation at best.

The cost of acquiring most types of resource data is relatively high, especially at finer levels of detail. Remote sensing technology, while not a panacea, can provide demonstrable reductions in the costs of data acquisition for some types of natural resource information.[1,2,3,4] It must, however, be used in an appropriate context with realistic expectations.

One of the principal areas where the potential application of remotely sensed data is being developed is in the generation of land use, or more precisely, land cover information.[5,6,7,8,9,10] Traditional data gathering methods, ranging from "windshield surveys" to low altitude photography, are generally too expensive and time consuming to perform more than once, if at all. The NASA Earth Resources Program, however, has significantly changed this situation. The synoptic, repetitive coverage of high resolution sensors on satellite platforms has made the collection, analysis, and dissemination of comprehensive regional land use data practical and cost-effective for the first time. Recognizing this potential, the South Dakota State Planning Bureau and the EROS Data Center undertook a cooperative land use demonstration project. Together they formulated the framework for the South Dakota Land Use and Natural Resource Inventory and Information System. Objectives were developed, and a three phase program designed.

Initially, three information sources are being tapped for this project. LANDSAT data, in digital and photographic formats, is being used to provide statewide land cover information at several levels of detail. High altitude

photography will be used for more detailed large area analyses, and for verification of the results produced using smaller scale imagery. Conventional low altitude photography will be used for detailed small area analyses in selected urban and critical areas. Each sensor will be used at the most appropriate and cost effective scale, so that the intrinsic advantages of each may be fully exploited.

OBJECTIVES

During the formulation of the program, an attempt was made to develop a realistic set of goals and objectives. The result is shown in Figure 1. The emphasis of the objectives was to address natural resource information needs with what were felt to be practical applications of remotely sensed data. To date, this has been borne out.

The overall goal of the program has been to provide detailed, accurate land cover and natural resource information to improve and support governmental decision making, the comprehensive planning process, and state and local land use planning and policy formulation. Conventional data sources were inadequate to meet these needs. Where information existed at all, it was often dated, inaccurate, of insufficient detail, or a combination of the three. It was necessary, therefore, to develop new data sources. Remote sensing technology provided the only viable alternative in a sparsely settled state such as South Dakota.

PROGRAM

A three phase program was designed to operationalize the South Dakota Land Use and Natural Resource Inventory and Information System. Phase I has essentially been completed. Phases II and III are scheduled to run concurrently with fiscal years 1976 and 1977, respectively.

Phase I

Two major tasks were completed in Phase I. A statewide Level I inventory was visually interpreted from LANDSAT imagery. Level II and partial Level III information was digitally interpreted from LANDSAT computer compatible tapes for selected priority areas. The generalized information flows for this phase are depicted in Figure 2.

Visual interpretation.- Visual interpretation was done on color enhanced LANDSAT imagery at a scale of 1:250,000. A diazo process was used for the color enhancement, with MSS5 in positive red and MSS7 in negative blue being sandwiched to create a false color composite. These composites, produced from 1:1,000,000 positive transparencies, were then copied onto 35MM slides, one per quadrant, or four per scene. The actual interpretation was done using a rear projection technique. (see Figure 3) The slide image was then projected onto special composite chronaflex 1:250,000 USGS base maps, with the land use data interpreted in quarter section cells (160 acres) and drafted onto a mylar overlay. The overlays were then color coded, generalized, redrafted, and mosaicked at 1:500,000 using a cartographic projector. This was sent to the printer for final map reproduction at a scale of 1:1,000,000.

Digital interpretation.- Within the land use inventory program, the LANDSAT Imagery Analysis Package (LIMAP) was used for the analysis and display of LANDSAT CCTs. This system was developed by the principal author, with the exception of the clustering and discriminant function algorithms which were adapted from LARSYS. The generalized analysis procedure used is shown in Figure 4. Selected priority areas were categorized on a pixel by pixel basis, with display scales ranging from 1:24,000 (1.1 acre cells) to 1:500,000 (40 acre cells).

Analysis procedure: The first step in the analysis procedure consists of joining and reformatting the raw multispectral data. This is essentially a housekeeping function, making the data easier to store, access, and use. If coverage of the study area (usually a county or multicounty area) requires the use of consecutive images, the scenes are merged and the overlap discarded. Fortunately, all but one of South Dakota's counties are entirely within consecutive images. The problem of joining side-by-side images was safely avoided.

The next step consists of removing the spatial distortion present in the data. The distortion present can be attributed, for the most part, to three factors: the motion of the spacecraft, the rotation of the earth, and the angle of the satellite's orbit.[11] The algorithm performs a linear rectification on a nearest neighbor basis, with the output being properly north-south and east-west oriented. This reorientation would be a trivial matter, were it not for the large amount of information in each scene. Even though a simplified geometric correction procedure is used, the rectification of 3 million pixels takes well over an hour of computer time on a moderate sized computer with limited main storage. Once the data is rectified, greyscale line printer maps are generated for MSS5 and MSS7, usually at 1:24,000 (all pixels) and/or 1:48,000 (25% sample).

The next step is the most crucial of the entire process. This is where the statistical definitions of the land use categories are developed. Greyscale maps of the study area for MSS5 and MSS7 are examined spectrally and associated with ground truth information, often high altitude aerial photography. Small windows, called training fields, are located on the map and are submitted to a clustering algorithm. Through a man-machine interactive procedure, an optimal set of spectral classes is obtained which is representative of the ground cover types to be identified. Finally, the spectral characteristics (statistics) of the selected categories are used to classify all of the data points in the study area using a Gaussian maximum likelihood classifier.

Display options: Once the study area is categorized, two display options are available: grey tone line printer maps, or color coded land use plots. Individual categories, all categories, or selected categories can be displayed in either mode. These displays and supporting statistics can be generated for the entire area, or selected portions of it, either rectangular or polygonal. The scale of line printer maps can be varied from approximately 1:24,000 to 1:144,000. The scale of the color plots can be varied from 1:24,000 to 1:500,000. The resolution for both output media can be varied between 1.1 and 40 acres. An aggregation algorithm creates multipixel cells as required. This program allows user specification of decision rules, automatic creation of combination categories when ties occur, or a combination of the two approaches, as requested at the time of execution. Examples of several types of hard copy are presented in the Initial Results section.

Phase II

Figure 5 illustrates the information flows of Phase II. During this phase, land uses in the remainder of the state will be analysed digitally to Level II and partial Level III, except in large homogenous areas, such as arid grasslands, where computer processing is deemed superfluous. NASA high altitude imagery will be systematically utilized to verify digitally produced information. Where LANDSAT digital processing is found to be inadequate, one of two courses will be followed. Where the classification is satisfactory, with limited areas of confusion, high altitude imagery will be used to resolve any discrepancies present. Current budget and work program plans include the acquisition of hardware which will permit data refinement in an interactive mode. If the digital classification is unacceptable, high altitude imagery will be visually interpreted, classified, digitized and prepared for entry into the information system.

An inventory of existing resource data will be undertaken during this phase. This is primarily in preparation for Phase III, when much of this data will be digitized and entered into the system. In addition, a land capability/suitability study will be done for a metropolitan area in the state. Appropriate natural resource data for the county will be selected and entered into the system. An overlay technique will be employed to reveal the intrinsic suitabilities and limitations for both urban and rural development. Alternative land development plans, and a package of appropriate policies to guide in the implementation of the selected alternatives will be presented to district, county, and municipal planning agencies.

The final major activity in this phase will be the visual interpretation of high altitude photography. Selected urban and critical areas will be categorized on the basis of quarter acre cells (approximately 30 x 30 meters). The basic interpretation technique will be the same as used on the LANDSAT imagery, with 1:24,000 quad maps replacing the 1:250,000 base maps. Upon completion of the interpretation, the land use and other resource data will be entered into the information system.

Phase III

During the final implementation phase, the breadth and depth of information available within the system will be greatly enhanced. The anticipated information flows are shown in Figure 6.

Level III land use information will be completed for the entire state. LANDSAT digital data interpreted in earlier phases will be adequate for most rural areas. Data for urban and critical areas will be interpreted from high altitude photography. Low altitude missions will be flown as required to meet special data needs. Once the land use data base is completed, a two to five year update cycle is projected. The actual frequency will depend on two factors: the amount of change since the last update, and the anticipated development pressure.

Several types of natural resource data will be added during this phase. These include, but are not limited to, soils data, topographic data, geologic data, hydrologic data, climatic data, surface and subsurface resource data, air and water quality data, and ownership type data. The presence of this data within the information system will allow a wide variety of detailed analyses to be performed as required for state and local planning and policy formulation.

The final major task performed in this phase will be the creation of linkages to the State Planning Bureau's Policy Information System. This system will contain comprehensive statewide social, economic, fiscal and demographic data. These linkages should greatly enhance the analytical capabilities of both systems, providing a basis for social, economic, and environmental impact assessment of alternative policy decisions.

INITIAL RESULTS

Central South Dakota

Analysis of a multi-county area in central South Dakota was recently completed. A single scene was selected for this analysis--May 15, 1973 (scene ID 1296-17014). All processing and display generation for this study area was performed by the LANDSAT Imagery Analysis Package.

Figures 7 and 8 show grey tone 25% sample line printer maps for Cow Creek Township in Sully County. The rectified data for MSS5 and MSS7 are displayed. The raw data was sliced on the basis of a visual examination of one dimensional histograms, and assigned to one of the five grey levels present.

Figure 9 is a single category map of bare soil in Cow Creek Township. For this display, the data has been aggregated into 4.4 acre cells (2 x 2 pixels). The scale of the original on this map, as in the previous two, is approximately 1:48,000. Figure 10 is an all category all pixel land use plot for the same township, (original scale = 1:62,500) and Figure 11 contains the legend for this plot.

Figure 12 consists of an all category plot of a major portion of Sully County at an original scale of 1:250,000, and Figure 13 contains the legend for this plot. Pixels have been aggregated into 10 acre cells (3 x 3 pixels) for this display. Cow Creek Township has been outlined for comparitive purposes.

Figure 14 is a listing of the land use categories which are being interpreted from LANDSAT CCTs with limited supplemental information. Higher resolution data sources would be required for the interpretation of more detailed information. This classification system is adapted from the Anderson system.[12]

Sioux Falls Analysis

As a comparison to the work being done at the State Planning Bureau, it was decided to run a comparison analysis using LARSYS 3.1 on the terminal at the EROS Data Center.

The area chosen for processing at EROS is located in the eastern portion of the state. Two LANDSAT-1 scenes were chosen for the analysis--August 15, 1972 (scene ID 1023-16433) and May 30, 1973 (scene ID 1311-16441).

Preprocessing.- The four bands of digital data from each scene were temporally overlayed, e.g., the data points were spatially registered to create a combined data set. The data were then geometrically corrected -- skew removed, oriented north-south, and scaled to 1:24,000 for line printer character maps.

Ground control/ground truth.- Important for the selection of training and test fields and overall assessment of classification accuracy was the assembly of a ground control aggregate and subsequent transfer of necessary ground truth information to the ground control. Nine U.S. Geological Survey 7.5 minute topographic guadrangles were trimmed and mosaicked to form a 1:24,000 scale ground control aggregate, the same scale as line printer character maps generated from the LANDSAT analysis. Ground truth available for the analysis included high altitude, color infrared aerial photography flown by NASA in 1970. Certain land use information, including location of industrial/commercial areas, newer housing, and older housing, were extracted from the aerial photography and indicated on the quadrangle-mosaic.

Training field selection.- Greyscale lineprinter character maps of the study area were generated for bands 5 and 7 for both August and May. Training fields were located for each of the land uses to be identified. Precise location of the training fields was possible by overlaying the greyscale maps with the ground control/ground truth aggregate on a light table. Training fields for commercial/industrial areas, newer housing, and older housing (divided into two distinct spectral classes because of differing tree canopy cover) were located on the band 5 greyscales, while the agriculture and forest samples were selected from band 7 maps. Because the May data included several small, cumulus clouds, training fields were located for two additional spectral classes, cloud and cloud shadow. Water bodies in the study area were not large enough to be spectrally identified.

A special problem arose in the selection of training fields to use for bi-temporal, agricultural land cover classification. The agricultural areas included a wide range of infrared reflectivity for both the August and May data sets. It was necessary, therefore, to create Gaussian subclasses of agricultural land cover types. Unfortunately, crop type information was not available to the analyst. Thus, the subclasses needed to be created solely on the basis of infrared reflectance. By careful and systematic scanning of both greyscale maps, agricultural field patterns were seen to be closely related to certain levels of reflectivity. The complete range of agricultural reflectivity in band 7 was ultimately divided into four levels for each date. The observation was made, moreover, that a given "level" (spectral class) of one date could be either of the other levels of the other date. For example, if crop type information had been available to the analyst, one of the sixteen possible combinations of agricultural bi-temporal land cover (16 combinations are possible, because of the 4 x 4 level matrix) might have been corn in August 1972, and dark bare soil in May 1973. One of the bi-temporal combinations, lowest reflectivity in August and highest in May, was not found to be a significant class for the analysis.

Location of training fields for the resultant fifteen agricultural classes completed the task of choosing representative areas to "train the computer" to identify the desired land uses--commercial/industrial, older housing (2 spectral classes), newer housing, forested, agriculture (15 spectral classes), cloud, and cloud shadow. The aggregate of training fields totaled 72, which included 1492 data points (1.0% of the 138,224 data points in the study area).

Statistics/Feature Selection.- Quantitative characterization of the land uses (spectral classes) was achieved by calculation of means for each class and covariance matrices for all pairs of classes. Using the spectral statistics, a feature selection processor was used to calculate separability coefficients for class pairs for 4-band combinations. The objective was to determine which 4-band set of pairs of spectral classes would be most separable (spectrally distinguishable). Selection of the "best 4" of the eight was largely arbitrary. Indeed, all eight channels might result in the most accurate maximum likelihood classification, but excessive computer time would have to be used. Previous studies have shown that four or five channels give acceptable classification results; use of more channels yields insignificant (small) gains in classification accuracy in consideration of the additional computer time used. Bands 5 and 7 from each date were chosen by the processor as the best four wavelengths. Divergence values (separability coefficients) for the 231 pairs of the 22 spectral classes were all satisfactory--213 pairs had values of 2000 (maximum separability; range is from 0 to 2000); 17 pairs had values from 1900 to 1999; and one pair (agricultural areas with very bright infrared reflectance in August and medium dark in May and medium-bright red in August and medium-dark red in May) had a value of 1750. The mean interclass divergence was 1997.

Maximum likelihood classification.- Because the classes were spectrally separable, as indicated by the feature selection processor, a Gaussian maximum likelihood classifier was used to categorize (classify) each of the data points in the study area into one of the twenty-two spectral classes. Class means and covariance matrices were used to create the decision boundaries. A common form of output of the classification results is a lineprinter alphanumeric character map, which displays the different land uses with different letters/symbols (Figure 15). A medium altitude aerial photograph of approximately the same area is included as Figure 16. Other possible output formats include lineprinter character maps with overprinting, color or black-and-white computer-driven plotter maps, color-coded photos from cathode ray tube (CRT) devices, and color-coded maps (film or print) from film recorders.

Classification Verification.- Quantitative assessment of classification accuracy was achieved by selection of rectangular areas, termed "test fields," for each of the land use classes. Two townships, Sioux Falls, and Mapleton, were chosen for the verification. The former is primarily urban while the latter is mostly rural. The townships contain 40,386 LANDSAT pixels, which represented 29 percent of the study area originally classified. Within the townships, 136 test fields were selected, containing 20,391 pixels or 51 percent of the two-township area.

Four generalized land use classes--commercial/industrial, forested, residential (3 spectral classes), and agricultural (15 spectral classes)--were tested for classification accuracy. Of the commercial/industrial pixels, 80 percent were correctly classified; 81 percent of the residential pixels were correct; forested was 69 percent; and agriculture 85 percent. The overall classification accuracy of test fields was 84 percent.

Classification results: Discussion.- Although a classification accuracy of 85 percent is satisfactory for regional resource inventories, it is appropriate to discuss sources of classification error. One problem is largely a

matter of definition of land uses versus spectral reflectance. New industrial parks, for example, typically have extensive landscaping, resulting in large expanses of green vegetation. In such areas, the buildings and parking lots will be accurately classified, but the surrounding lawns and shrubbery are usually classified as parks or agriculture. Another problem of definition arises in agricultural areas. A number of earth surface features--country road right-of-ways, narrow shelterbelts, homesteads, stock ponds, weedy areas in fields, and small alluvial depressions--are usually too small to be spectrally identifiable at LANDSAT resolution, yet are large enough to influence the reflectance values of LANDSAT pixels and will often result in classification error.

Another problem in LANDSAT classification is border pixels. Data points which are collected on boundaries between two land uses often have reflectance values characteristic of neither land use. Erroneous classifications sometimes result.

Within residential areas, a particular classification problem arises in transitional areas between distinct regions of older housing, characterized by mature tree canopy, and distinct areas of newer housing, characterized by large lawns and brightly reflecting rooftops and streets. Between these two land uses there is often an area with "medium" sized trees. Such areas are often misclassified as agricultural land cover.

Additional classification iterations.- Attempts were made to refine the classification results, by redefinition of the statistical characterization of the land use (spectral) classes. This was accomplished by altering the set of training fields for certain classes.

Initially, the training fields for three of the fifteen agricultural classes were changed. Overall classification accuracy was increased one percent to 85 percent, but class accuracy for two land uses--commercial/industrial and residential--decreased, from 80 to 65 percent and from 81 to 80 percent, respectively. Agricultural areas were more accurately identified increasing from 85 to 86 percent, while forested accuracy remained stable at 69 percent.

Training fields were altered for industrial/commercial areas for the third iteration, resulting in no change in overall classification accuracy. Industrial/commercial identification was increased to 69 percent accuracy, while percentages for the other three land uses were unchanged.

The results of this comparative analysis will be included in the Phase I report generated by the Bureau.

CONCLUSION

The Land Use and Natural Resource Inventory and Information System will substantially increase the amount and extent of resource information readily available to all levels of government in South Dakota. The natural resource management process will proceed on a stronger informational base. The speed with which information can be generated and the depth to which it can be analysed will be greatly improved.

Such an information system has many potential applications. Some of those projected for this demonstration include:

--All the county land use inventories completed so far are to be included as integral parts of the land use component of the respective counties'

comprehensive plans.

--During Phase II of the program, LANDSAT data from 1972 and 1975 is going to be used to determine how much rangeland has been broken in an arid country, mainly due to the skyrocketing price of small grains. If current drought conditions persist, a report detailing recently plowed areas with excessive slopes will be prepared and submitted to the Soil Conservation Service for further action.

--During the latter part of Phase II of the program, when a wider range of data is available within the system, a land suitability study will be undertaken for a large, predominantly urban county.

--During Phase III, formal linkages will be developed between the Land Use and Natural Resource Information System, and the state's Policy Information System. The latter system is composed primarily of social, economic, fiscal, and demographic data. These linkages should greatly enhance the analytical capabilities of both systems.

Other applications which may be worthy of investigation include:

--The Commission of School and Public Lands, responsible for the management of over one million acres of grassland, has expressed interest in rangeland condition evaluations.

--A Planning District Director has suggested using drainage basin data in conjunction with delineations of bare soil areas from early spring imagery to detect soil erosion areas in order to enhance lake preservation efforts.

A generalized summary of projected applications appears in Figure 17.

It is the authors' hope that this effort, and others like it, will lead to an increased recognition of the role of remotely sensed data, as well as other types of quantitative resource information, in federal, state, and local governmental planning and policy formulation. If governmental natural resources planning is to proceed on a firm informational foundation, "planners intuition" must be replaced by more quantitative data sources. The overriding concern of this demonstration project is to make a significant contribution to that end.

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REFERENCES

[1]Brooner, William G. and David A. Nichols. "Considerations and Techniques for Incorporating Remotely Sensed Imagery into the Land Resource Management Process." Remote Sensing of Earth Resources, Vol. I, ed. by F. Shakrokhi, The University of Tennessee, Tullahoma, Tennessee, 1972.

[2]Nunnally, N. "Interpreting Land Use from Remote Sensor Imagery" Remote Sensing Techniques for Environmental Analysis, ed. by John E. Elstes and Leslie W. Serger, Hamilton Publishing Company, Santa Barbara, California, 1974.

[3]Shakrokhi, F. and J.P. Rhudy. "Remote Sensing Techniques in Evaluating Earth Resources -- A Study of Potential Uses of Remote Sensing for Southeastern U.S." Remote Sensing of Earth Resources, Vol. I, ed. by F. Shakrokhi The University of Tennessee, Tullahoma, Tennessee, 1972.

[4]Craib, Kenneth B. "The Cost-Effectiveness of High Altitude Systems for Regional Resource Assessment." Remote Sensing of Earth Resources, Vol. I, ed. by F. Shakrokhi, The University of Tennessee, Tullahoma, Tennessee, 1972.

[5]Vegas, Paul L. A Detailed Procedure for the Use of Small-Scale Photography in Land Use Classification, NASA TND-7542. NASA/Johnson Space Center, Houston, 1974.

[6]Alexander, Robert H. "CARETS-An Experimental Regional Information System Using ERTS Data." Third Earth Resources Technology Satellite - Symposium NASA/Goddard Space Flight Center, Washington, D.C. December, 1973.

[7]Simpson, Robert B. David T. Lindgren and William D. Goldstein. "Evaluation of ERTS-1 Data for Acquiring Land Use Data of Northern Megalopolis." Third Earth Resources Technology Satellite-1 Symposium, NASA/Goddard Space Flight Center, Washington, D.C., December, 1973.

[8]Place, John L. "Change in Land Use in the Phoenix (1:250,000) Quadrangle, Arizona Between 1970 and 1972: Successful Use of a Proposed Land Use Classification System." Symposium on Significant Results Obtained from the Earth Resource Technology Satellite-1. NASA/Goddard Space Flight Center, New Carrolton, Maryland, March, 1973.

[9]Landgrebe, David and Staff. "An Evaluation of Machine Processing Techniques of ERTS-1 Data for User Applications." Third Earth Resources Technology Satellite-1 Symposium, NASA/Goddard Space Flight Center, Washington, D.C., December, 1973.

[10]Todd, William J. and Marion F. Baumgardner. "Land Use Classification of Marion County, Indiana by Spectral Analysis of Digitized Satellite Data." Machine Processing of Remotely Sensed Data, Laboratory for Applications of Remote Sensing, Purdue University, West Lafayette, Indiana, October, 1973.

[11]NASA/Goddard Space Flight Center. ERTS Data User's Handbook, Document No. 715D4249. General Electric Space Division, Philadelphia, 1972.

[12]Anderson, James R., Ernest E. Hardy and John T. Roach. A Land Use Classification System for Use with Remote-Sensor Data, Geological Survey Circular 671. U.S. Geological Survey, Washington, D.C., 1972.

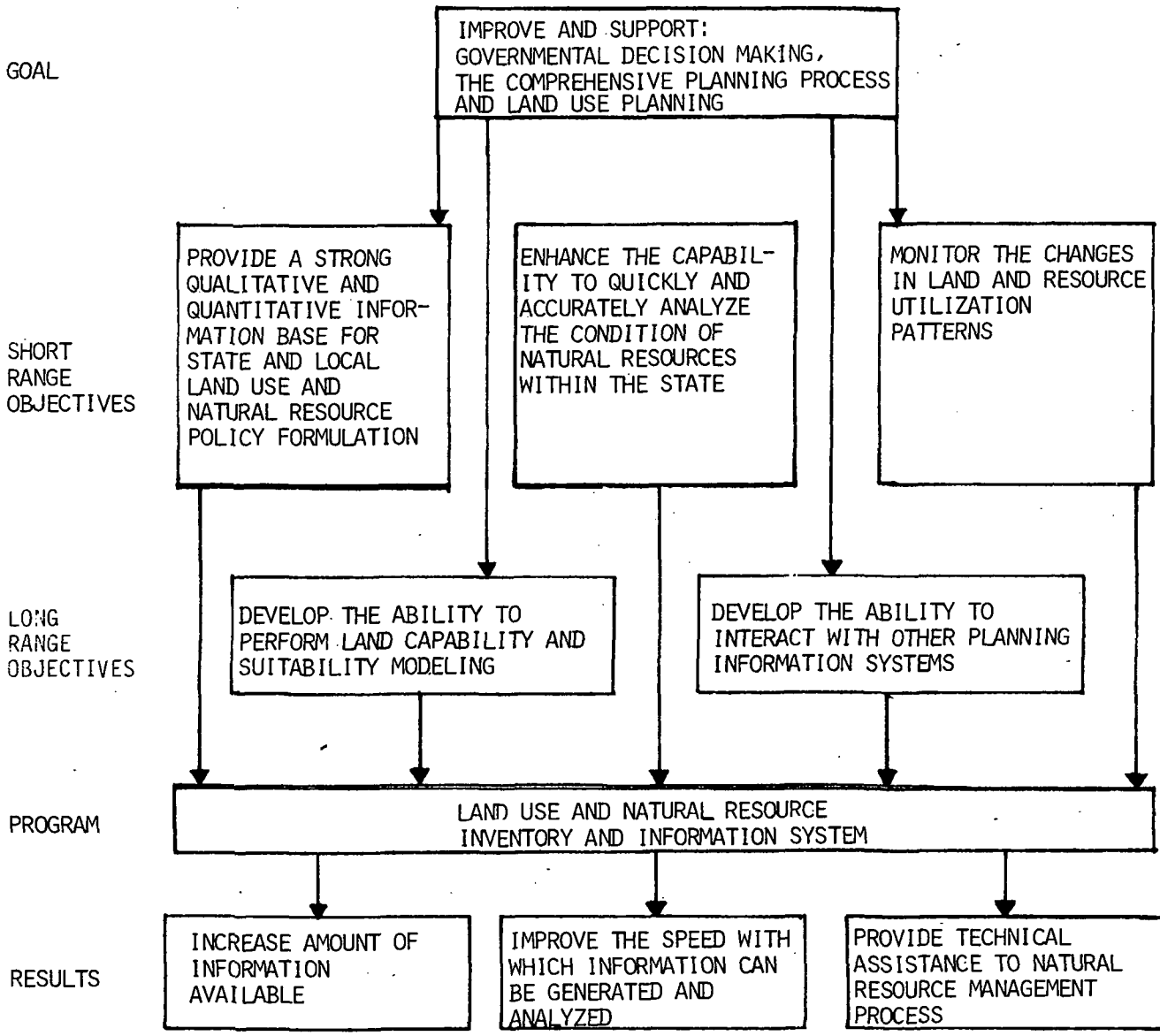


FIGURE 1.-GOAL AND OBJECTIVES OF THE SOUTH DAKOTA LAND USE AND NATURAL RESOURCE INVENTORY AND INFORMATION SYSTEM

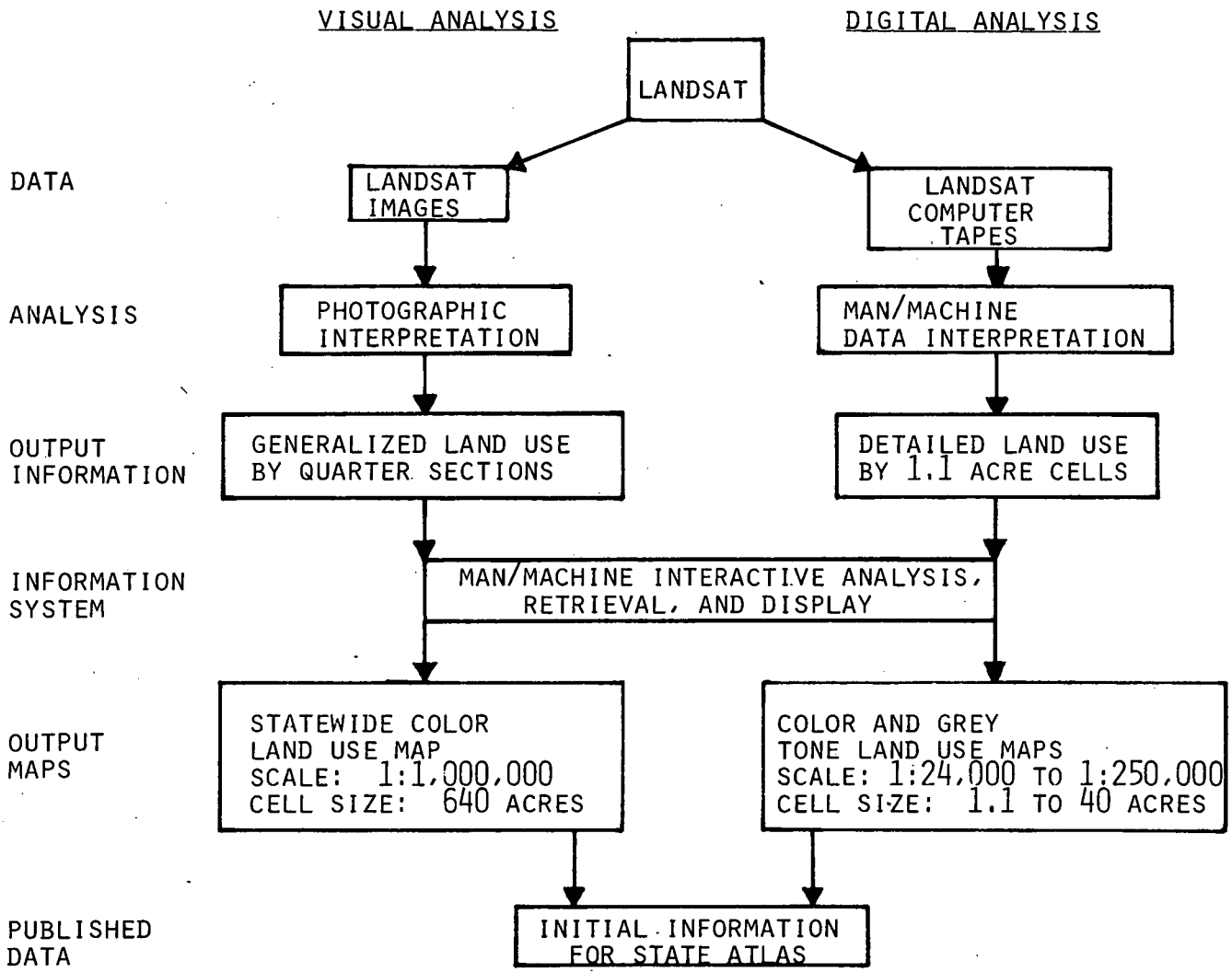


FIGURE 2.-INFORMATION FLOWS: PHASE I (FY 1975)

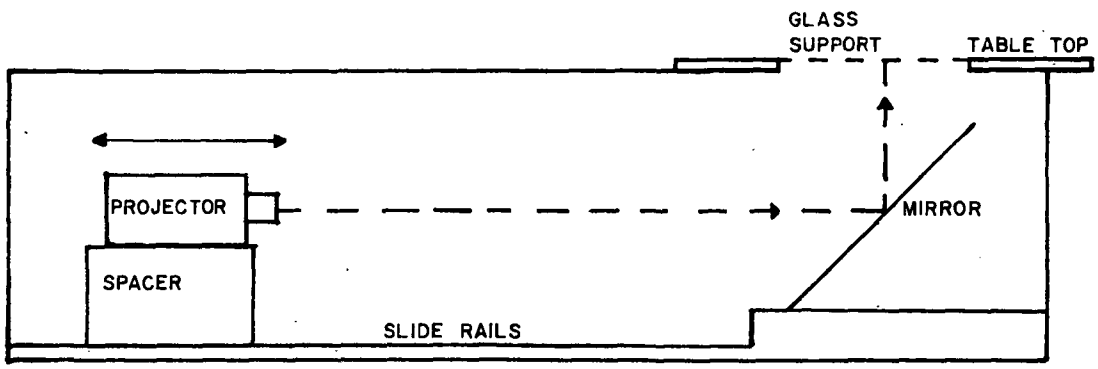


FIGURE 3.-REAR PROJECTION SYSTEM

DATA ACQUISITION

TAPE COPYING AND REFORMATTING

RECTIFICATION
(Elimination of data distortion)

SAMPLE DATA TO DEVELOP CATEGORIES

CATEGORIZE ENTIRE IMAGE, PRINT GREY TONE MAPS AND STATISTICS FOR RELEVANT PORTIONS OF IMAGE

PRODUCTION OF COLOR PLOTS FOR SELECTED AREAS
(Township base)

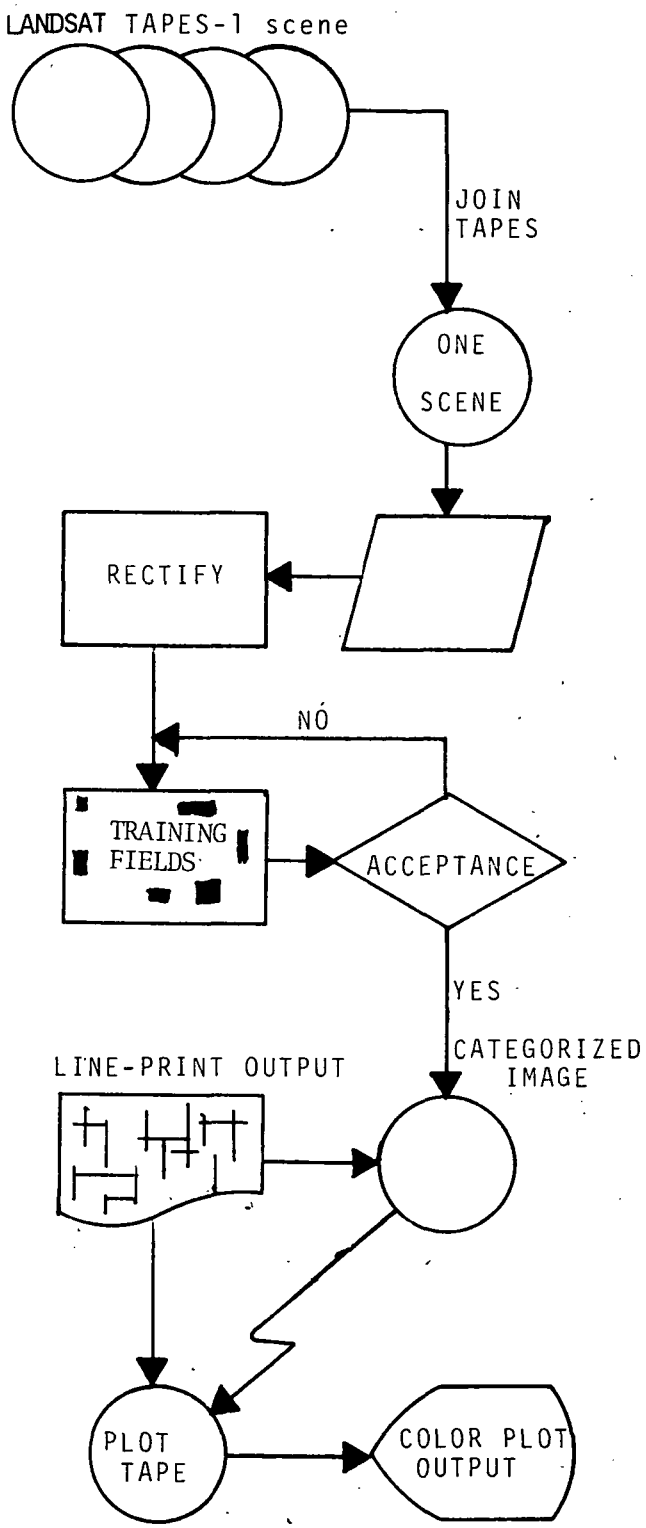


FIGURE 4.-LAND USE INVENTORY ANALYSIS PROCEDURE

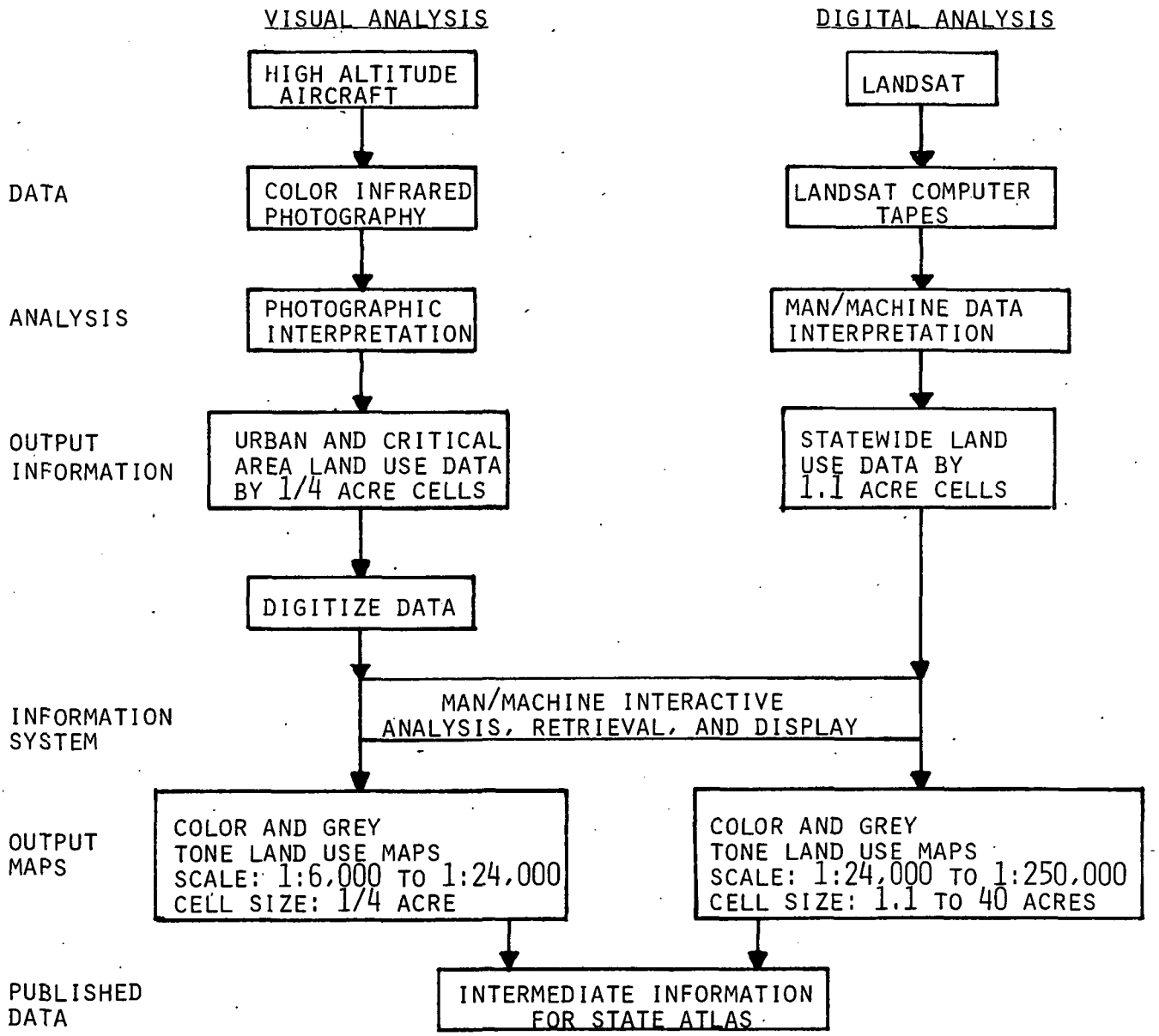


FIGURE 5.-INFORMATION FLOWS: PHASE II (FY 1976)

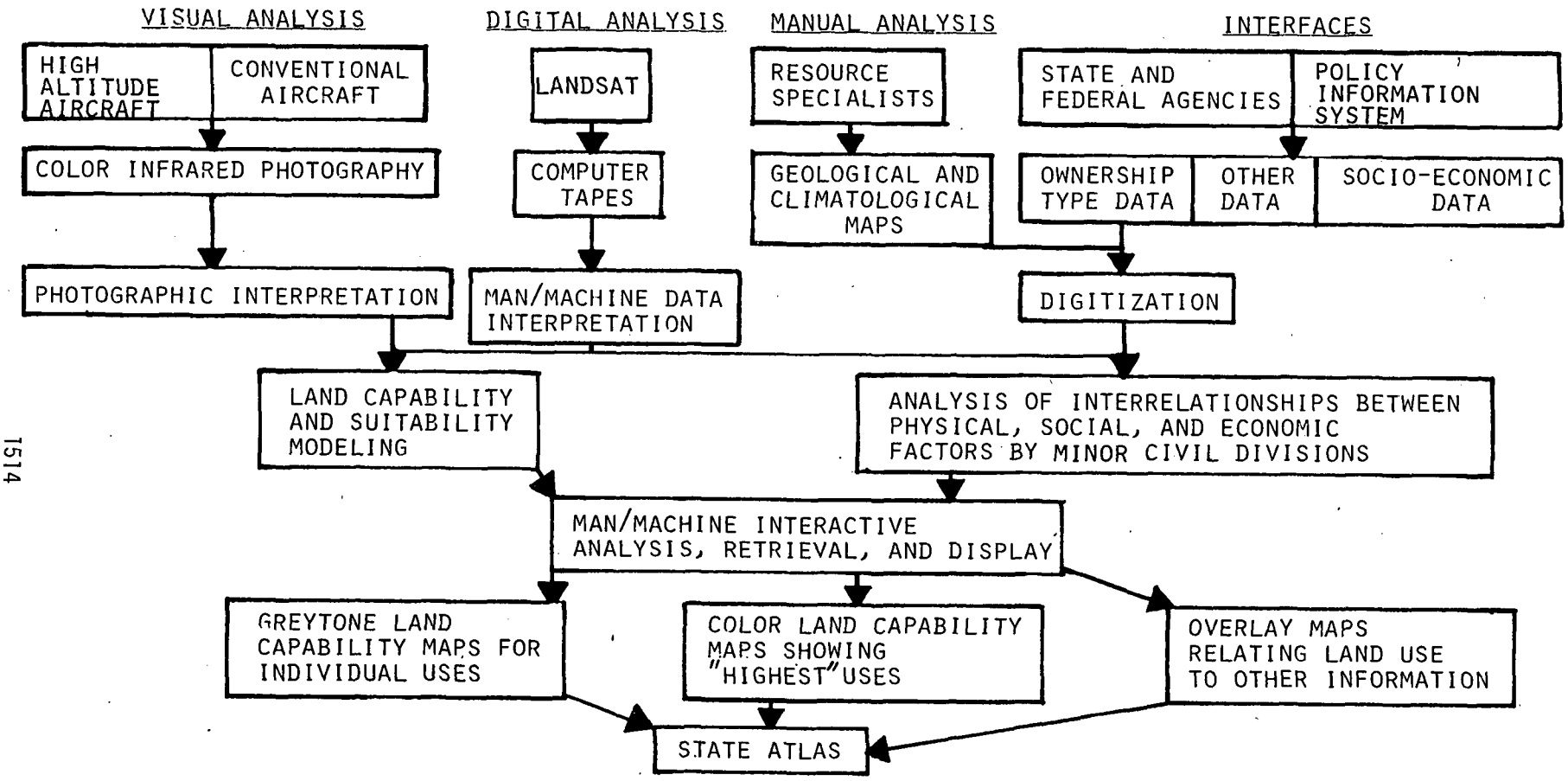


FIGURE 6.-INFORMATION FLOWS: PHASE III (FY 1977)

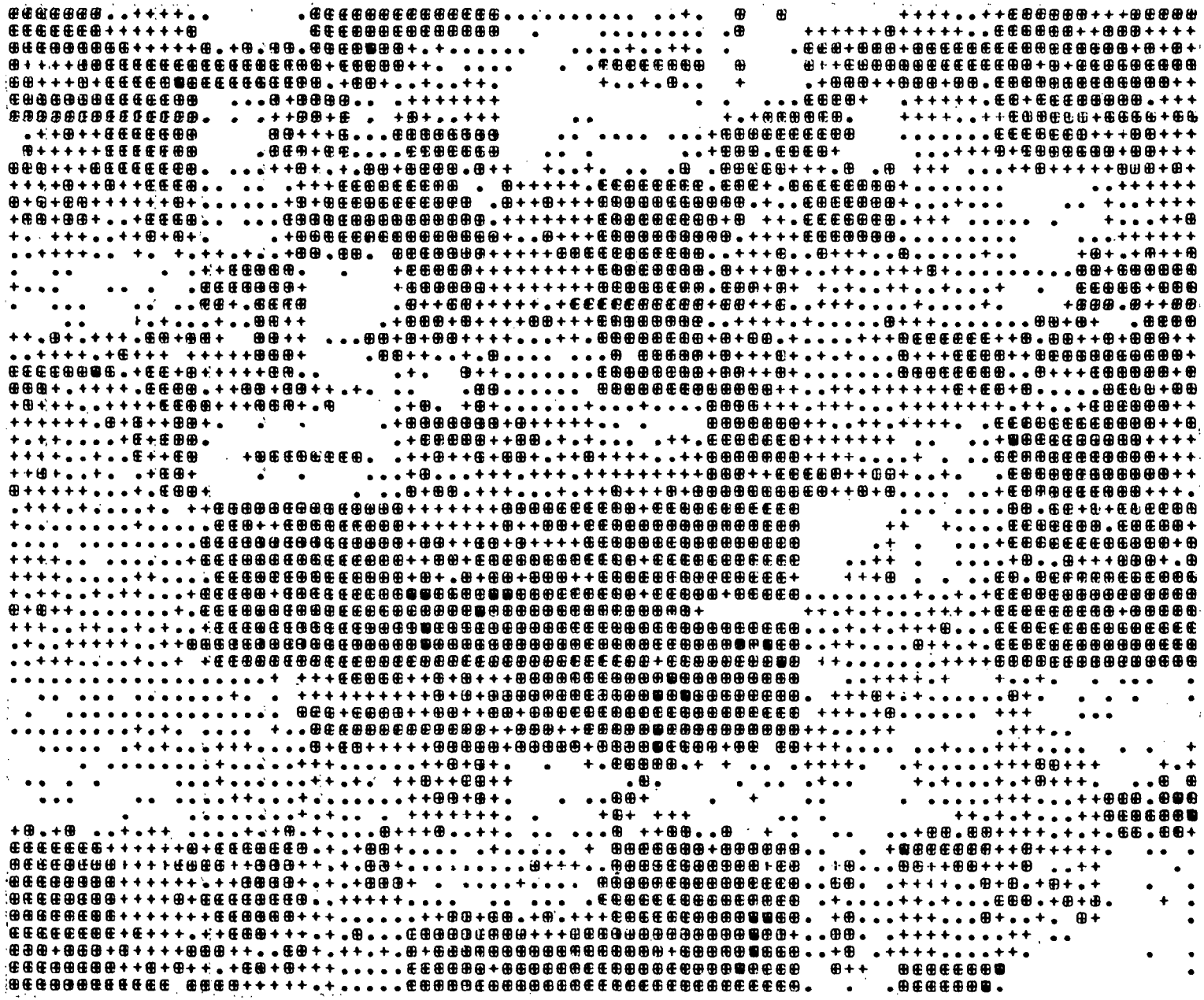


FIGURE 7.-25% SAMPLE GREY TONE LINE PRINTER MAP OF MSS5 FOR COW CREEK TOWNSHIP
(ORIGINAL SCALE APPROXIMATELY 1:48,000)

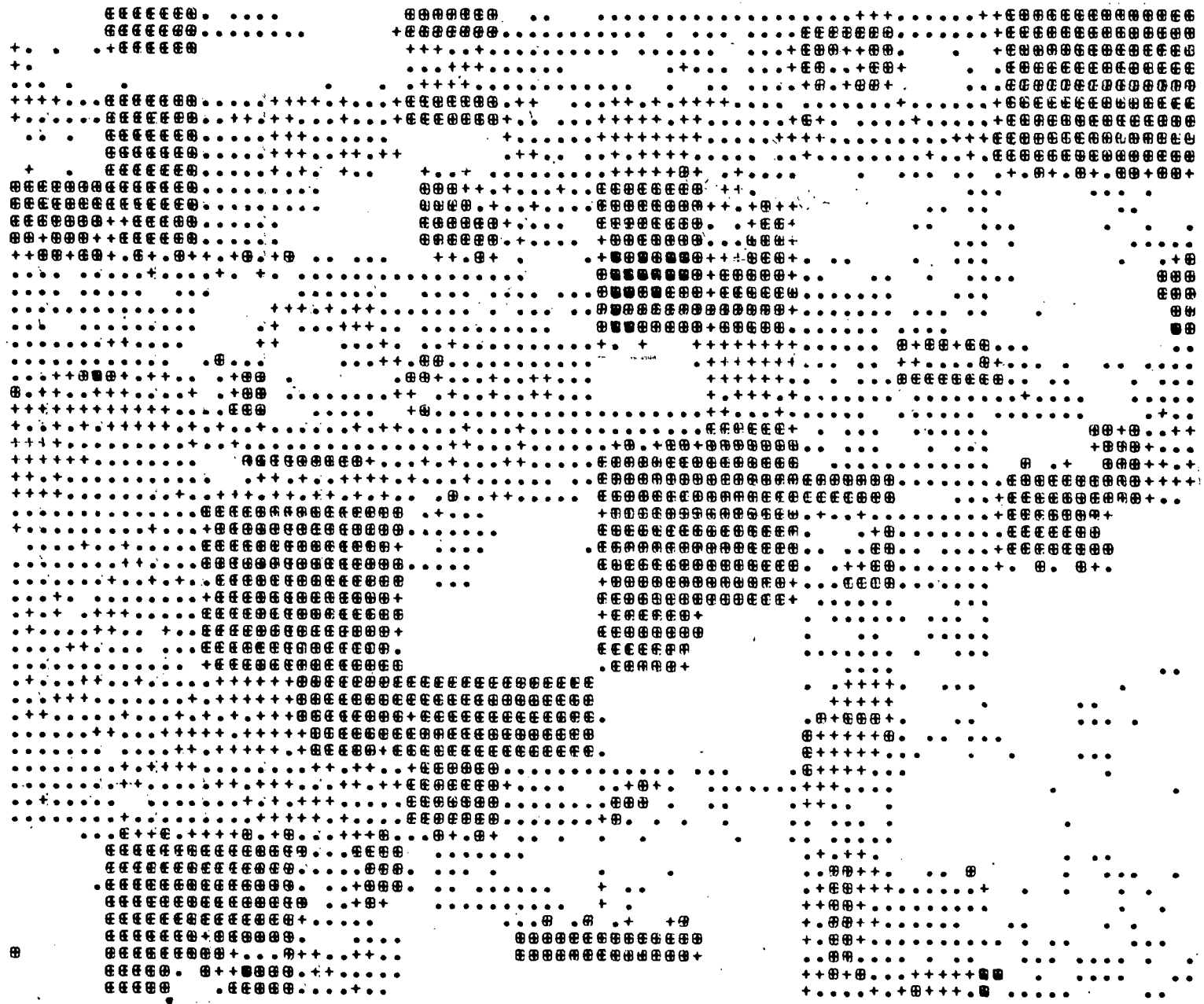


FIGURE 8.-25% SAMPLE GREY TONE LINE PRINTER MAP OF MSS7 FOR COW CREEK TOWNSHIP
(ORIGINAL SCALE APPROXIMATELY 1:48,000)



FIGURE 9.-SINGLE CATEGORY LINE PRINTER MAP OF BARE SOIL FOR COW CREEK TOWNSHIP-4.4 ACRE CELLS (ORIGINAL SCALE APPROXIMATELY 1:48,000)



FIGURE 10.- CODED ALL CATEGORY ALL PIXEL LAND USE PLOT FOR COW CREEK TOWNSHIP (ORIGINAL SCALE = 1:62,500)

CATEGORY		FREQ	PCT
500	WATER	8.	0.04
211 CR	BARE SOIL	5643.	28.12
300	RANGELAND	11157.	55.60
213 CR	SMALL GRAINS	3260.	16.24

FIGURE 11.- LEGEND FOR COW CREEK TOWNSHIP PLOT



FIGURE 12.- CODED ALL CATEGORY LAND USE PLOT FOR SULLY COUNTY. COW CREEK TOWNSHIP IS OUTLINED. CELL SIXE IS 10 ACRES. (ORIGINAL SCALE = 1:250,000)

CATEGORY		FREQ	PCT
500	WATER	3531.	6.91
211 CR	BARE SOIL	12709.	24.86
300	RANGELAND	30492.	59.64
213 CR	SMALL GRAINS	4398.	8.60

FIGURE 13.- LEGEND FOR SULLY COUNTY PLOT

LEVEL I	LEVEL II	LEVEL III
000 Uncategorized		
100 Urban and Built Up		
	110 UB Residential-Old	
	115 UB Residential-New	
	120 UB Commercial	
	130 UB Industrial	
	140 UB Transportation	
	160 UB Mixed	
	170 UB Other	
200 Agriculture		
	210 AG Cropland	
		211 CR Bare Soil
		212 CR Fallow
		213 CR Spring Grains
		214 CR Winter Grains
		215 CR Corn
	240 AG Other	
300 Rangeland		
400 Forest Land		
	410 FL Deciduous	
	420 FL Evergreen	
	430 FL Mixed	
500 Water		
600 Wetland		
	630 WT Riverbottom	
700 Barren Land		

Figure 14.-Land use categories, as adapted from Anderson system[12]

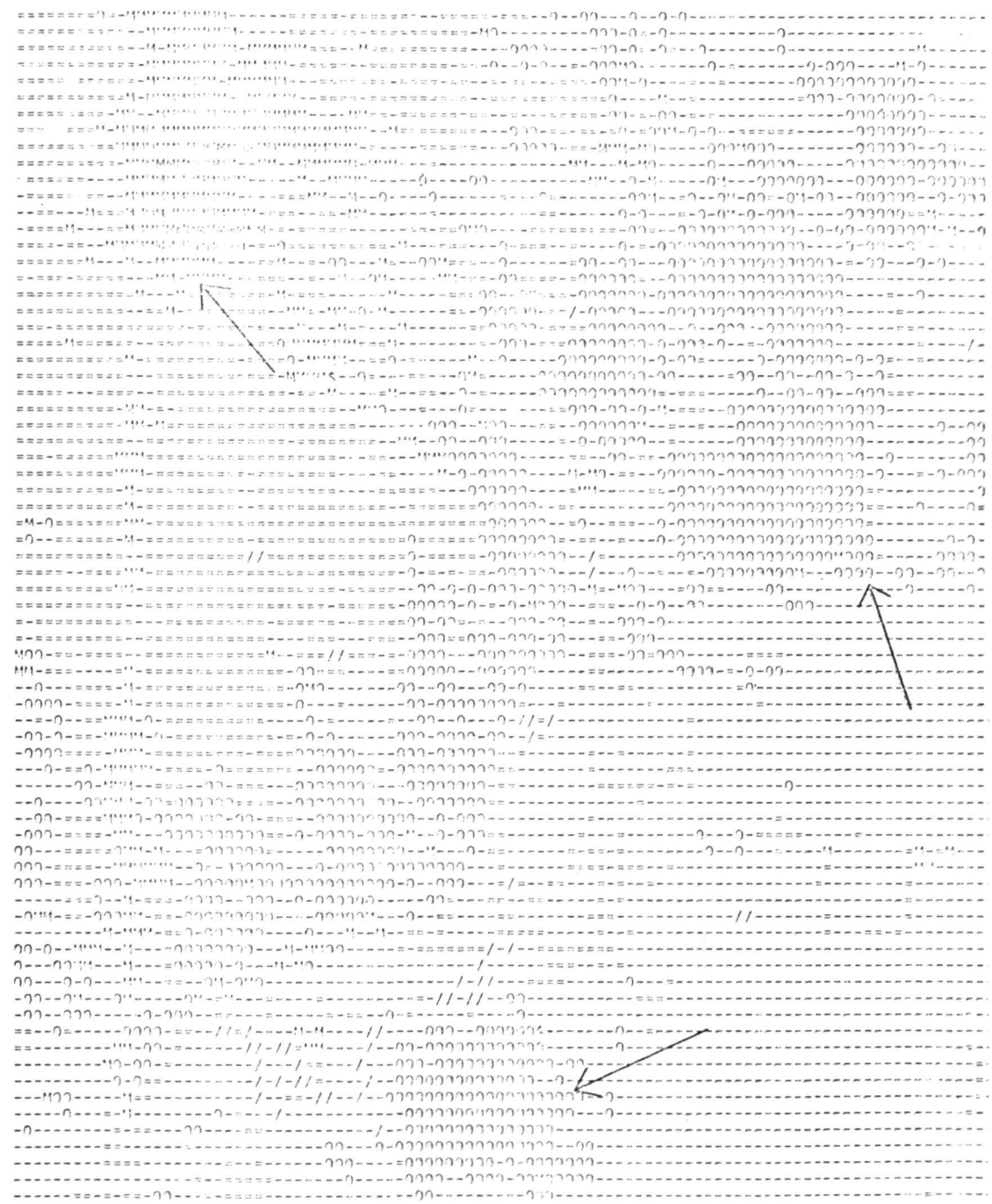


FIGURE 15.-COMPUTER-AIDED CLASSIFICATION OF BITEMPORAL (AUGUST, 1972 AND MAY, 1973) LANDSAT DATA COLLECTED OVER SIOUX FALLS.
SYMBOLS: M-COMMERCIAL/INDUSTRIAL;
O-NEW RESIDENTIAL;
=-OLD RESIDENTIAL;
/-FORESTED;
--AGRICULTURE/GRASSY.
ARROWS INDICATE LOCATION OF FEATURES SHOWN IN FIGURE 16

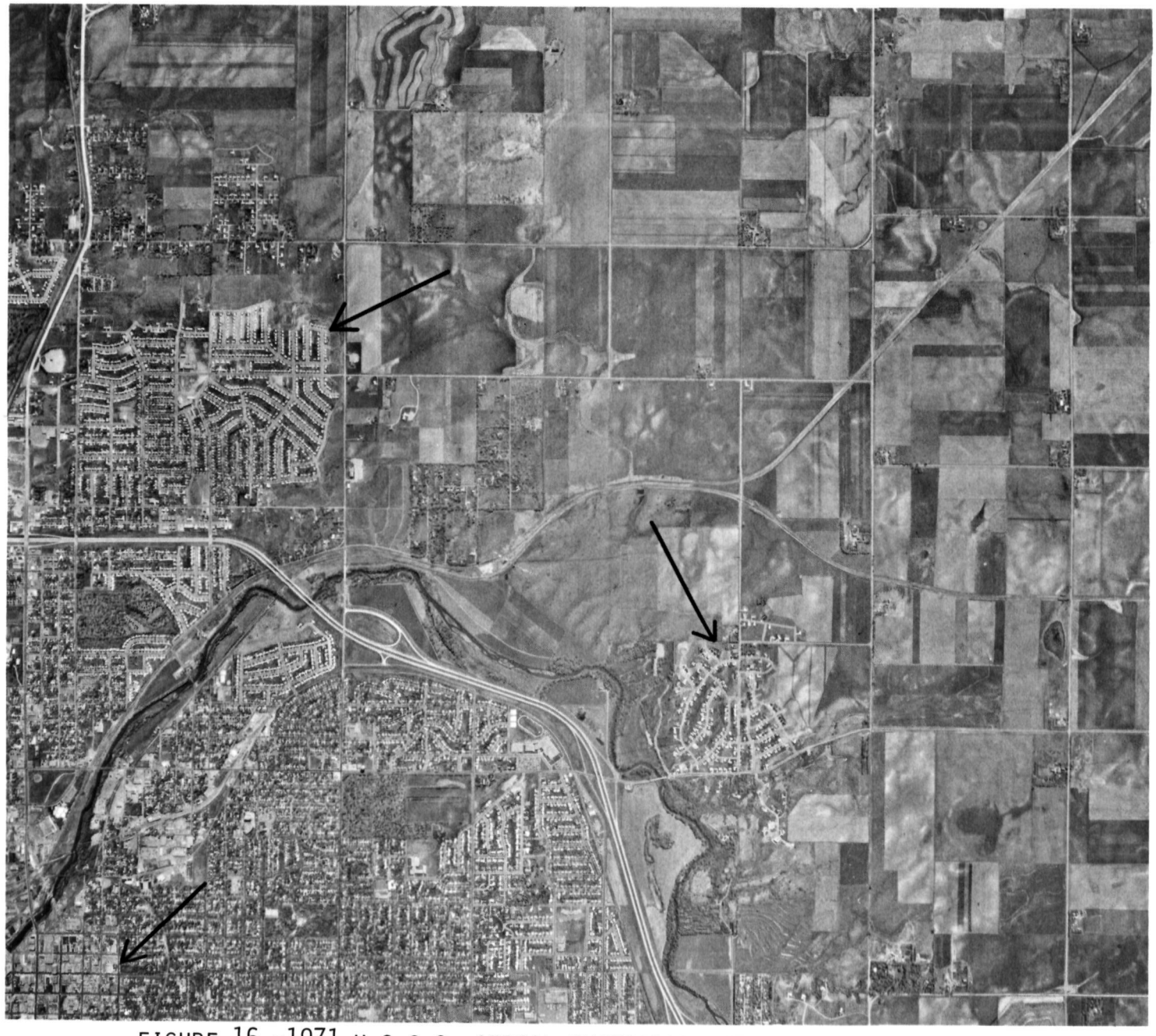


FIGURE 16.-1971 U.S.G.S. AERIAL PHOTOGRAPH OF A PORTION OF SIOUX FALLS, SOUTH DAKOTA. ARROWS INDICATE LOCATION OF SOME FEATURES SHOWN IN FIGURE 15.

State Policy

- -Resource development policy
- -Land use policy
- -Critical area identification and evaluation
- -Natural resource management

Local Planning

- -Comprehensive land use and resource planning
- -Land use change analysis
- -Local technical assistance
- -Flood plain delineation
- -Land use suitability studies

Environmental Monitoring

- -Critical area identification and evaluation
- -Water resources planning
- -Water quality monitoring
- -Wildlife habitat evaluation

Agriculture

- -Land capability analysis
- -Crop inventories and yield forecasting
- -Rangeland condition evaluation
- -Pest infestation and crop disease monitoring
- -Conservation practice monitoring

Economic Development

- -Transportation and Transmission corridor studies
- -Land capability and suitability modeling
- -State development policy
- -Future alternatives projection

Figure 17.-Potential uses of information produced by South Dakota Land Use and Natural Resource Inventory and Information System.

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AN EXAMINATION OF THE POTENTIAL APPLICATIONS OF AUTOMATIC CLASSIFICATION TECHNIQUES TO GEORGIA MANAGEMENT PROBLEMS

L-2

By Bruce Q. Rado, Department of Natural Resources,
Office of Planning and Research, Atlanta, Georgia 30334

ABSTRACT

Recent State and federal legislation, along with improved methods and techniques for data acquisition and manipulation, has created new opportunities for State, regional, and local planning.

One such opportunity included representatives from the State of Georgia and other southeastern states who participated in a workshop at the NASA/Earth Resources Laboratory in Bay St. Louis, Mississippi. The purpose of the workshop was to become more familiar with automatic classification techniques as they may relate to future statewide planning systems.

Aside from the lectures which the group was to receive, the opportunity was also offered to process on LANDSAT tape, provided we acquired the tape and the training samples.

During the three days at the NASA facility, the group also received an intensive briefing on how this system operates, the types of equipment and associated costs, the more scientific method of obtaining training samples, and a presentation of the assorted case studies as they pertain to different disciplines. The latter proved to be quite beneficial, because we were able to relate to specific issues and formulate potential applications which the automatic classification system might have.

The results of the classified tape were then presented to individuals in the various State, university, and regional planning agencies. Many of these groups will react favorably provided we can get the land cover classifications we desire to acceptable geographic reference standards. This is especially true if the system is flexible and meets the decision-maker's needs for data at a low cost. The new tape, once classified, can be reproduced at a variety of scales through electronic expansion without loss of information and detail. This group further decided that an investigation as to the system's full potential had merit. The opportunity for further investigation has been secured in the form of technology transfer between the State of Georgia and the Earth Resources Laboratory of NASA.

INTRODUCTION*

Recent State and federal legislation, along with empirical methods and techniques for data acquisition and manipulation, has created new opportunities for State, regional, and local planning.

Moreover, proposed federal and State land use legislation, which has resulted from the pressures of rapid growth and development of the environment, has caused an evaluation as to the responsibility of various governmental agencies. It is these responsibilities, along with a recognition of specific issues and possible data sources, which require further attention.

The objective of this paper is to present the applications of automatic classification techniques to Georgia management problems. Therefore, discussions will be presented as to some of the issues which need to be addressed in a statewide system, and how automatic classification techniques can be made compatible with such a system. The observations regarding the implementation of an automatic classification system in Georgia are based upon preliminary investigations with NASA and potential users throughout the State.

As appropriate, this paper presents information derived from the Georgia Resource Assessment Program and other statewide agency activities.

*The author wishes to acknowledge the contributions of Charles M. Parrish, III, Director, Office of Planning and Research, Georgia Department of Natural Resources, for his ideas presented herein and also express thanks to other members of the Department for their review of a preliminary draft.

For the past two years, the Georgia Department of Natural Resources, Office of Planning and Research, has been engaged in a statewide Resource Assessment Program. This Program, which incorporates much of the data and results produced by the Department's engineers, geologists, biologists, and planners, as well as data from other agencies such as the USDA/Soil Conservation Service, has begun to serve as a data input for the Department of Natural Resources as well as other agencies of state government when engaging in various types of natural resource planning efforts.

The concept of the Resource Assessment is to provide data and standards for agencies to implement in their project design. In this way, these projects will be improved from a natural resource perspective. This should also result in a more efficient environmental impact statement review since we would be better able to support the alternatives which the implementing agency recommends.

Under its present structure, the Resource Assessment Program has four elements incorporated into its design.

- The first element, known as the Resource Index, is a publication entitled A Guide to the Natural Resource Information of Georgia Volumes I and II. This publication serves as a guide to all existing natural resource information contained in published reports which pertain to Georgia. Its purpose is to present professional individuals with a quick but thorough knowledge of all the available natural resource data within the State.

- The second element, known as the Resource Inventory, is the objective and reproducible mapping of soils, vegetation, watersheds, geology, and other important data on a statewide basis. This data is mapped at a scale of 1" = 1 mile and 1:250,000 (1" = approximately 4 miles) with minimum map units of about 40 acres.

- The third element, known as Application, deals with the recommended techniques for using the data base for the determination of relationships between natural resources and land disturbing activities.

- The fourth element, known as the Resource Research, involves researching and analyzing the experiences of other state and federal groups relating to manual and computer systems design and remote sensing.

These applications of computer and manual techniques can take several forms, ranging from the more qualitative overlay to the highly technical simulation model having several objectives such as vulnerability, attractiveness, suitability, and carrying capacity. The user will ultimately be responsible for selecting those techniques which best serve his needs. In addition, User Guides to Soils and Vegetation Information have been prepared which describe the procedures involved in the data collection phase of the Resource Assessment along with possible methods of application for each of the data categories.

To date, soils and vegetation information have been mapped by county to a scale of 1" = 1 mile. Soils are mapped by associations which are derived from either the modern or general soils maps. The classifications were grouped according to the soil's texture and physical properties as determined by the USDA/SCS. Vegetation information was mapped by associations from the 1" = 1 mile USDA/ASCS aerial photographic mosaics which varied from one to approximately ten years in age.

The purpose of the Resource Assessment is to provide data in a common format for use by State, regional, and local groups when determining areas of natural resources vulnerability, determining the location of potential areas for sanitary landfill operations, and use as a data source in the A-95 and environmental impact statement process. At the interdepartmental level, the data has served as a natural resource base to the State's Coastal Zone Management Program and the Department of Transportation's Land Use Allocation Model. At the regional and local levels, the information has been in great demand by individuals working for public agencies and consulting firms engaged in a myriad of applications ranging from federally contracted projects to those of more local significance. One example is the use of our 1" = 1 mile data, augmented with other sources, by the Georgia Mountains Area Planning and Development Commission for determining the impacts of proposed projects within its 13 counties.

Given the common data base system requirements which several federal, state, regional and local governments, and consulting firms have for certain data, it can be anticipated that a need exists for an expanded data base which can supply existing programs with better quality data on a more timely and iterative basis. An automatic classification system utilizing LANDSAT data should allow us the flexibility of developing certain classification systems on an individual project basis, should provide us with objective and iterative data for a relatively inexpensive cost and should be geographically referenced to acceptable standards compatible with other data in both grid and polygon form. Many of these issues are fairly straightforward, and if given proper consideration, can be adequately addressed. There is, however, one technical issue which could possibly prove to be the greatest limiting factor in the design of a statewide system, that is the ability to economically collect and update the data bank.

Until recently, most states engaging in such a system have had few alternatives as to how natural resource data is collected. The standard procedure, which was also used for our vegetation mapping, has been to assemble university students and low altitude photographs and begin the rigorous interpretive process. The obvious disadvantages are that such a process is expensive to update and is quite difficult to ensure compatible results.

Presently, there are several methods which collect and manipulate data for natural resource decisions. In an attempt to look for new and better ways of improving and synthesizing data aquisition, storage and retrieval, a task force from the Southern Growth Policy Board sub-committee on Land Use and Carrying Capacity Studies was invited to a three day workshop at the Earth Resources Laboratory of NASA in Bay St. Louis, Mississippi. The purpose of the workshop was to examine automatic classification techniques as they may relate to future statewide information and natural resource planning systems.

During the three days at the NASA facility, the group received an intensive briefing on how this system operates, the types of equipment and the associated costs, the more scientific method of obtaining training samples, and a presentation of the assorted case studies as they pertained to application by different disciplines. The latter proved to be quite beneficial since we were able to relate to specific issues and formulate potential applications which the automatic classification system might have.

Aside from the three days of lectures which we were to receive, the opportunity was also offered to process one LANDSAT tape (approximately 100 miles by 25 nautical miles), providing we did the training samples and acquired the computer compatible tape. An effort was then launched which would give us access to a computer tape and teach us the art of collecting training samples.

Of the LANDSAT tapes we had access to, it was decided to pick the coastal frame which includes practically all of Georgia's islands and marshes, while extending inland to include the new I-95, the cities of Savannah and Brunswick, plus the river swamps and areas of upland vegetation. Before the data classifications were chosen, an attempt was made to determine the types of data which would be useful for the various State agencies. The following categories seemed appropriate: sand and spoil areas, salt water marsh grass, brackish marsh grass, lowland river swamp vegetation, upland grass areas, different densities of urban cover and upland vegetation by associations (i.e. upland hardwood, pine mixed age, pine even age, mixed hardwoods and pines). The training samples, which numbered approximately 75, were then aggregated until we had approximately five for each classification category containing a minimum of 15-25 acres and a maximum of several hundred acres. The total amount of time for collecting these training samples was about two days.

During our second evening at the facility, the training samples were located on the unclassified data tape which was displayed on the image display system. We were on the system for approximately three hours which enabled us to take all the 75 pre-selected training samples plus some additional new ones. The following morning the statistical information was ready for review and analysis. Each training sample was then reviewed for any bi-model characteristics while the divergence statistics were checked to determine if further training samples were needed and the number of groups which could be categorized. Following a review of the statistics, the classifications were grouped and the data was classified using spectral pattern recognition programs. The actual printing of the unclassified display (see figure 1) and the classified product (see figure 2) to a scale of 1:250,000 (1" = approximately 4 miles) was then performed on the film recorder. The classified final product displayed the following categories: low density urban, (light blue), higher density urban (cyan), beach and spoil areas (white,), upland grass areas (yellow), salt water marsh grasses (red), brackish marsh grasses (magenta), water bodies (blue), and upland vegetation (green). There was an extremely small area which was displayed as unclassified (black).

The results of this demonstration tape have proved impressive, although there were categories which we were unable to separate due to the time of year the tape was derived. Since we were using an October 26, 1973 tape, the specific signatures of the upland vegetation were difficult to separate. The problem of separating the vegetation associations was further extenuated because

of the quality of our training samples. Our review of NASA and USGS research products has indicated that given proper time of year tapes, that vegetation associations can be separated. Therefore, reaching this objective will depend upon the successful grouping of the various vegetation associations which we were unable to obtain from this tape. Our NASA work should provide us with the opportunity to separate vegetation associations provided we obtain better training samples, become more familiar with our training sites, and are able to obtain updates on these sites.

In arriving at any conclusions about an automatic classification system, one might decide that a system which is flexible, rapid, and inexpensive from a personnel and operating cost standpoint could be more desirable than a system lacking these advantages but able to obtain a greater degree of accuracy. An important characteristic of this computer implemented technique is that it is iterative and the newly acquired data can possibly be formatted for direct input into a system for analysis without digitizing or resorting to hand-drawn maps. Another advantage of this automatic classification technique is that it will operate on any multispectral scanner data whether it be derived from medium or high flight aircraft or from a satellite. One issue of concern is a comparison of the scanner capabilities of LANDSAT versus Skylab and aircraft data (see figure 3). The recent work by Coker et al. appears to indicate that if a Skylab or a aircraft-type scanner could be designed for operational LANDSAT application, then products of greater utility to Georgia, and possibly other states, could be derived.

The classified tape was presented to individuals in the various State, university, and regional planning agencies. Many of these groups will react favorably provided we can get the land cover classifications we desire to acceptable geographic reference standards. This is especially true if the system is flexible and meets the decision-maker's needs for data at a low cost. The new tape, once classified, can be reproduced at a variety of scales through electronic expansion without loss of information and detail. This group further decided that an investigation as to the system's full potential had merit. The opportunity for further investigation has been secured in the form of technology transfer between the State of Georgia and the Earth Resources Laboratory of NASA.

To date, several meetings have been held with interested agency personnel to assist us in relating potential applications to the automatic classification technology. These meetings have addressed the uses and data needs which the various agency representatives plan to investigate. Below is a preliminary list of the potential uses which our study will initially address:

- agriculture

  crop acreage and yield predictions
  disease infestation studies

- forestry

  crop inventories and yield predictions
  percent crown density
  age of species
  disease infestation studies
  undesirable species studies
  wildlife habitat areas

water resources

salinity rates
flood plain studies
estuary and river swamp studies
marshland protection (monitoring change)

environmental planning

land use classification systems
environmental impact statements and A-95 reviews
monitoring urban growth
septic tank feasibility studies
natural areas and ecosystem studies
heritage trust sites
resource assessment program

geology

beach erosion and deposition of rivers
monitor channel morphology
land reclamation studies
delineation of shoal areas

The Department of Natural Resources' Resource Assessment Program is serving as a natural resource planning element within our State. It is an issue-oriented program which relies upon data from other sources whenever available and develops its own data only when it is feasible. Its objective is to assist in resolving resource management problems regarding statewide concern such as: selecting feasible alternatives for highway corridors, selecting new airport sites, developing shoreline management programs for the Corps of Engineers, developing regional land-use programs and developing an analysis of natural resource impacts for projects such as reservoir construction, small watershed projects and the location of major industry.

To date there has been a substantial use of the data in its present form. But the problem with the existing data is that as the users become more sophisticated, they will prefer, and probably be required, to quantify rather than qualify their results. If we can obtain the desired classifications and solve any geographical control problems to acceptable minimum map accuracy standards, then we expect that automatic classification techniques can provide us with a more acceptable product.

There is, however, a limited regional scale of planning which can be addressed at scales such as 1" = 1 mile or 1:250,000. We must realize that the type of decisions at this scale will always be too general for site-specific areas. Although we never designed or anticipated that our system would provide us with site-specific data, it is anticipated that an automatic classification system which is flexible, iterative, digitized, and with a smaller minimum unit than our current hand-drawn maps, should be of great utility.

One example which the Resource Assessment Program can compare is the existing 1" = 1 mile vegetation maps prepared for each of the State's 159 counties.

The cost of this project was approximately $30,000, which did not include administrative costs to DNR, or about $190.00 per county. Each map was prepared on clear mylar while color was applied to delineate the appropriate vegetation associations. This exercise has proven quite valuable since it not only provides the State with one fairly consistent mapping effort, but also since it provides good indicator information for large portions of the State which, until now, had little land cover data. These hand-produced maps still have problems since they were drawn by different individuals, interpreted from the "best available photography" and the cost of updating would be expensive. These products would be more acceptable if improved sensors were able to provide iterative coverage for particular areas having site-specific problems.

These products should not only enable us to do more efficient work within our own departmental programs, but also enable us to provide better technical data and assistance to other public and private concerns.

In the early stages of this project we fully realized the need to meet with potential users and to gain some insight into the types of applications which could be anticipated. Although these uses serve a valuable function, it is probably more important to be able to identify those goals, objectives, target dates and issues which are needed to assist in making a final decision on whether such a statewide system is warranted.

The Georgia Department of Transportation is presently developing with the University of Georgia a transportation planning land-use simulation model. This model will enable the DOT to determine the impact of transportation corridors on a statewide basis upon land-use, population, housing and employment.

The model is an iterative land-use simulation model and contains a series of self-contained, interrelated submodels. The submodels to be developed are employment, population, housing, land-use, and transportation. The model's structure will enable it to run with alternative forecasting techniques and policy assumptions.

Presently, there is an inadequate supply of reliable land-cover data. Therefore, the only data which has been collected are gross classifications of available information such as soils, slope, vegetation, and a differentiation between urban and rural areas. These gross classifications indicate that a problem exists in obtaining and managing data for the modeling process.

The implementation of an automatic classification system could aid the modeling effort by increasing the amount and detail of land-cover data. This information would be able to provide a land-cover classification system delineating spatial and statistical data on a pixel basis.

The possible advantages of an iterative automatic classification system appear numerous, especially when comparing it to the current methods of manual acquisition. Those advantages include a savings of money and time, better detail of data, and a greater opportunity for sophistication and quantification.

Other DNR applications should be in addressing environmental impact statements and A-95 reviews. One recent example, which may have had application to automatic classification techniques, is a 60,000 acre small watershed project proposed by

the USDA/Soil Conservation Service for the purposes of watershed protection and flood prevention. This coastal watershed has approximately 242,000 acres containing three primary vegetation habitats: lowland hardwoods, mixed hardwoods with pines and pine flatwoods. The area to be drained is about 90% mixed hardwoods with pines and 10% lowland hardwoods. If an automatic classification system were operational it could have possibly provided us with the following spatial data and statistical acreage information: location of drainage ways containing lowland hardwoods, areas inundated by water at various times of year, a delineation of wildlife habitats, and a determination of the salt and fresh water interfaces. This data would have enabled us to make a better quantitative determination of the project's effects as required by the National Environmental Policy Act of 1969. This system should also allow us to monitor the impacts of increased peak flows on the estuary and low flow conditions on the river swamps and tributaries.

The Department has also indicated its intention to increase the total acreage of land for wildlife management from 1.2 to 3.0 million acres. A major portion of this increase could come through leases from land owners associated with the wood products industry. Accurate and current land-cover data would greatly facilitate the identification of suitable lands for possible acquisition or lease. The types of data required include vegetation associations and age of stands, the proximity of any potential area to developed lands, and the location of surface water bodies. If this data can be obtained on a timely and cost-effective basis, then our management program could be substantially improved.

In the coastal marshlands, the automatic classification system should assist us in determining seasonal patterns and changes in the relationship between upland development and the marsh. It should also assist in monitoring and evaluating the effects of federal disposal of dredge and fill on the marshes and coastal waters. Another opportunity is to spatially locate and survey where the wetlands are and how the management practices of adjacent states effect Georgia's marshes. One disadvantage of this system using LANDSAT data is the difficulty in locating small alterations which are beyond the satellite's present resolution and registration capabilities.

The agricultural community within our State is interested in examining automatic classification techniques since it appears to offer the opportunity to continually collect agricultural resource data resulting in more efficient inventory and management procedures. Research results to date indicate that remote sensing, either from aircraft or satellites, is beginning to play a significant role in agricultural operations provided high standards of accuracy can be achieved and if the cost to the users can be efficient. Listed below are a few of the issues which need to be addressed if LANDSAT data is to be applied for agricultural purposes in our state:

- higher spectral and spatial ($<$ 10-30 meters) resolution
- sensors capable of cloud penetration
- repetitive and dependable coverage at periods of better than 18 days
- thermal scanner capability
- better real-time data availability and processing capabilities

Currently, we are attempting to identify those issues which will need future attention. Until recently most departments of state government have been operating

within their own limited boundaries. Now, with the appearance of programs such as the Department of Transportation's Land Use Allocation Model, the Department of Natural Resources' Resource Assessment Program, the State Office of Planning and Budget's Coastal Zone Management Program, and legislation such as the National Environmental Policy Act of 1969, a new era of interdepartmental problem-solving is emerging. By nature, these projects tend to be more comprehensive in scope and demanding in terms of quality and quantity of data. Preliminary indications from these programs appear to be pointing out that traditional ways of collecting, disseminating, and manipulating data are rapidly becoming inadequate. It is therefore imperative that new options and a determination of their potentials be explored.

A first step in the investigation of any statewide system or subcomponents of that system, such as the NASA automatic classified system, is to answer the types of questions which Calkins discusses in this paper. These questions include such obvious, but all too often overlooked, issues such as "does the system meet the needs of the user"; "is the user constrained from using the system"; and "does the user have any incentive to use such a system?" If the answer to these questions is no, then we have an example which could indicate a design problem. Perhaps the system as originally implemented was never useful, or, the needs of the user changed while the system did not or could not change. Whatever the reason, these examples point to a greater need for participation and communication between the groups charged with financing, designing, and ultimate application of such a system. It is therefore imperative that a more three-dimensional approach to systems design be observed. This would include the above objectives while also taking into consideration issues such as: how to obtain user confidence, how to reduce duplication of efforts, how to input changing conditions during a study, and how more reliable data and systematic processing techniques can prove to make planning and its results more accountable.

In our NASA technology transfer project, it will be essential that potential users of the system document their particular areas of concern and that criteria for desired results be determined, it will then be necessary to hold workshops between the users and the individuals transferring the technology. This will result in discussions of potential applications and use of the system. The next step might be to determine what the results of the various disciplines have in common and how, if at all, a statewide system could be used to address the issues of single and multi-disciplinary projects.

Following a determination of the applications of the automatic classification system, another dimension needs to be analyzed. That is, how can other programs, which include either data and/or analytical techniques, be integrated with the automatic classification techniques to enable the various agency-collected data to compliment each other. One example might be, how can the information from the NASA automatic classification system be made compatible with that of the LUDA program being developed within the USGS? From a user perspective, it will be quite useful if the two systems are compatible. The most obvious reason being that the apparent advantage of the NASA automatic classification system is its ability to produce land-cover information, plus associated statistics, on a pixel basis for large regions with iterative capabilities. Although the land-cover classification may not be sufficient for certain applications in urban areas, it should prove adequate and flexible in its classification in regions of natural land-cover. When dealing with urban areas, the LUDA program could prove more

effective since it will map level II land uses* to 10 acre accuracy in urban areas and 40 acre accuracy in rural areas. In any event, there is a tremendous amount of work necessary to evaluate individual components and then their relationships to each other. Comparative analysis will be made in Georgia as to pros and cons of each of these systems for both urban and natural resource application.

In closing, there are possibly more questions to be asked than products to present. Listed below are a few questions which surface when considering the implementation of a statewide automatic classification system.

- If we decide that an automatic classification system will do the job for us, what guarantee do we have that LANDSAT will become operational?
- Do we need operational aircraft with an MSS scanner?
- Will anyone assist us in some of the equipment costs?
- Is private industry able to assist government in this effort at a price we can afford?
- How can we assist an individual such as a farmer, who has a problem on a given day if there is no satellite overpass?
- Will it be more appropriate to rent or purchase equipment such as a portable image display system (PIDS) and film writer?
- What type of output and format do we need?
- How do we set up a user system in terms of communicating and disseminating data?
- Is it more appropriate to have 1 system or several systems within the State?
- How do we effectively incorporate equipment deliveries and budget cycles into the operation?
- Will the state need to begin a LANDSAT tape library, and if so, how much will it cost on a yearly basis?
- How can we obtain tapes on a more timely basis from Goddard?
- What is the continuing need and appropriate role of manual interpretation?

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* Although the LUDA program claims to be mapping land use, probably the more appropriate term should be land-cover. This is suggested since the LUDA program will interpret from high altitude photographs without the needed element of field checking or other data sources.

There are several states which are either in the process of dealing with the issues in this paper or have already dealt with them. It is our hope that while dealing with these issues within our own State, that a forum be established for discussing and resolving these and other issues which are of mutual concern to all states.

BIBLIOGRAPHY

Calkins, Hugh W., "The Proposed Washington State Land Information Service", Bellevue, Washington, 1973.

Coker, A. E. et al., "Automatic Categorization of Land-Water Cover Types of the Green Types of the Green Swamp, Florida, Using Skylab Multispectral Scanner (S-192) Data", U.S. Geological Survey, Water Resources Division, August, 1974.

Colvocoresses, Alden P., "Recommended Specifications for a Follow on ERTS (ERTS-C) Satellite", U.S. Geological Survey National Center, Reston, Virginia, March, 1975.

Dueker, Kenneth J. et al., "Land Resource Information System: A Development and Demonstration for the State of Iowa", Institute of Urban and Regional Research, University of Iowa, Iowa City, Iowa, December, 1974.

Halperin, Mike, "Use of ERTS Land Use Information for Transportation Planning", Georgia Department of Transportation, Engineering Experiment Station, Georgia Institute of Technology, Atlanta, Georgia, December, 1974.

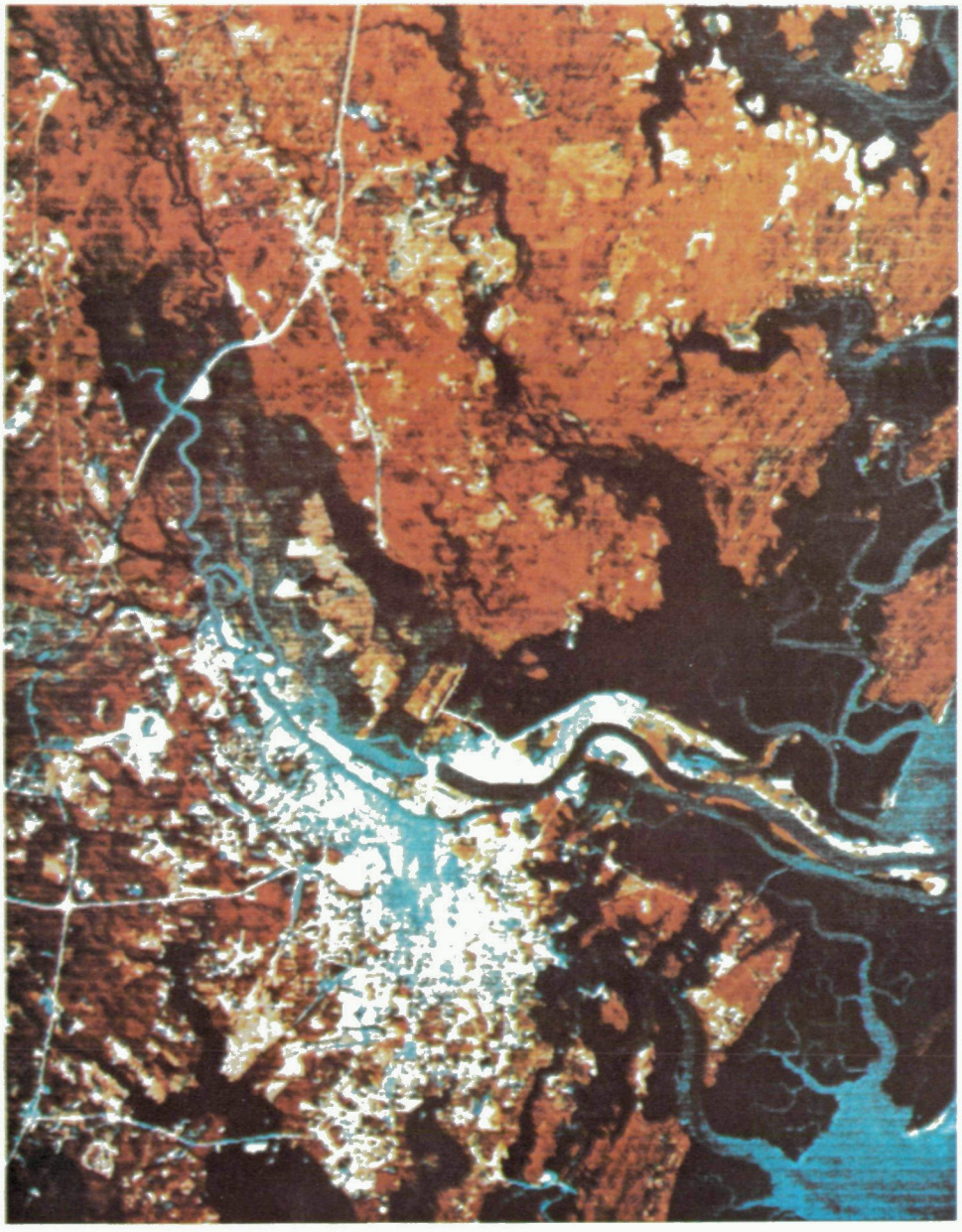
Joyce, T., Armond T., and Derbonne, J.D., "A Computer Implemented Land Use Classification Technique applied with ERTS Digital Data Acquired Over Southern Missouri", Lyndon B. Johnson Space Center, April, 1975.

Miller, Robert H., "The Significance of Remote Sensing Techniques for Agricultural, Forestry, and Rangeland Management", in American Society of Photogrammetry, proceedings, 41st Annual Meeting, March 9-14, 1975, pp. 119-206.

Smith, John E., "New Direction for Land-Related Planning Information Systems: A State Perspective", New York State Office of Planning Services, Albany, New York, October, 1974.

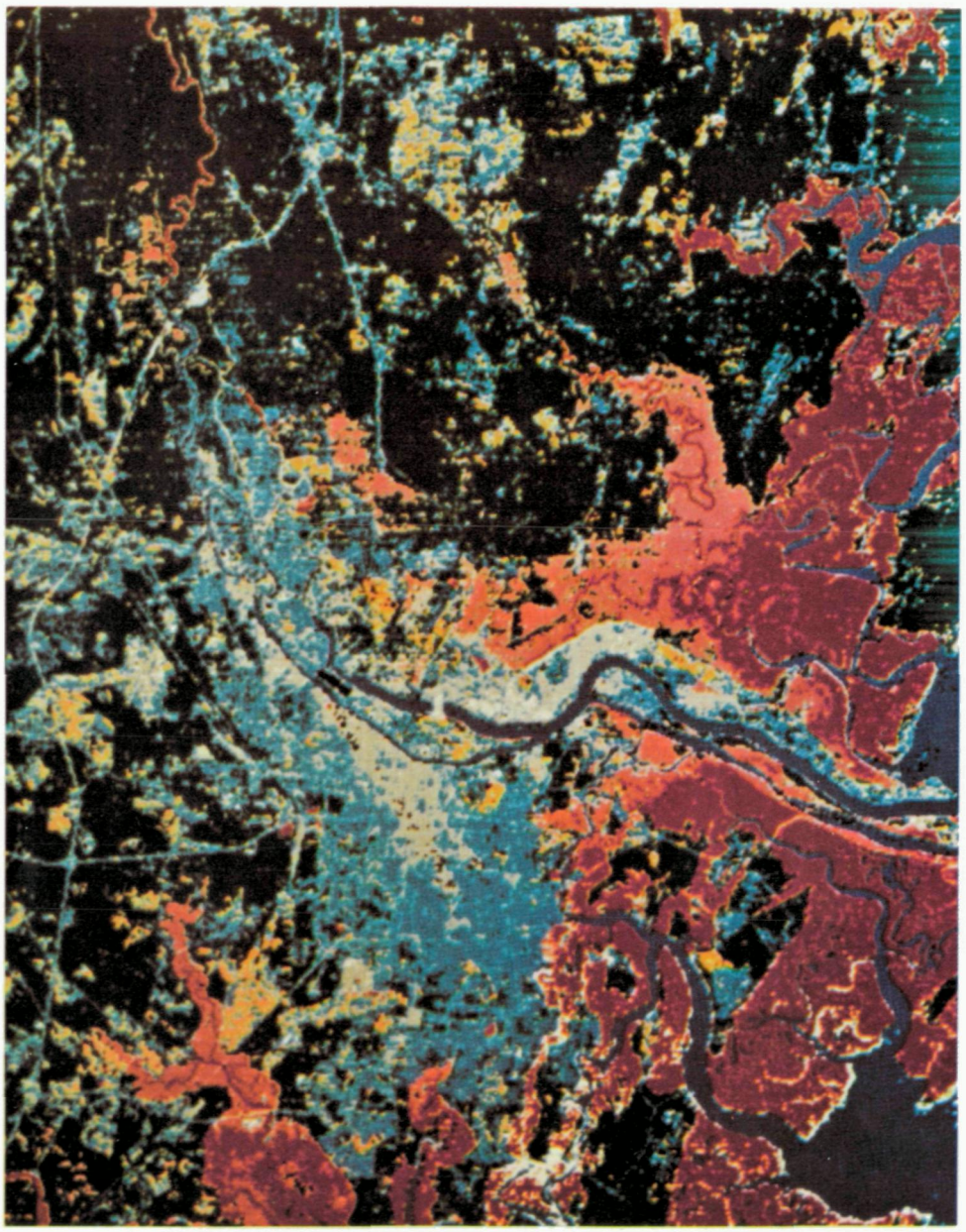
"Texas Remote Sensing Plan", Prepared by the Task Force on Remote Sensing for Submission to the Interagency Council on Natural Resources and the Environment, December, 1974.

Figure 1



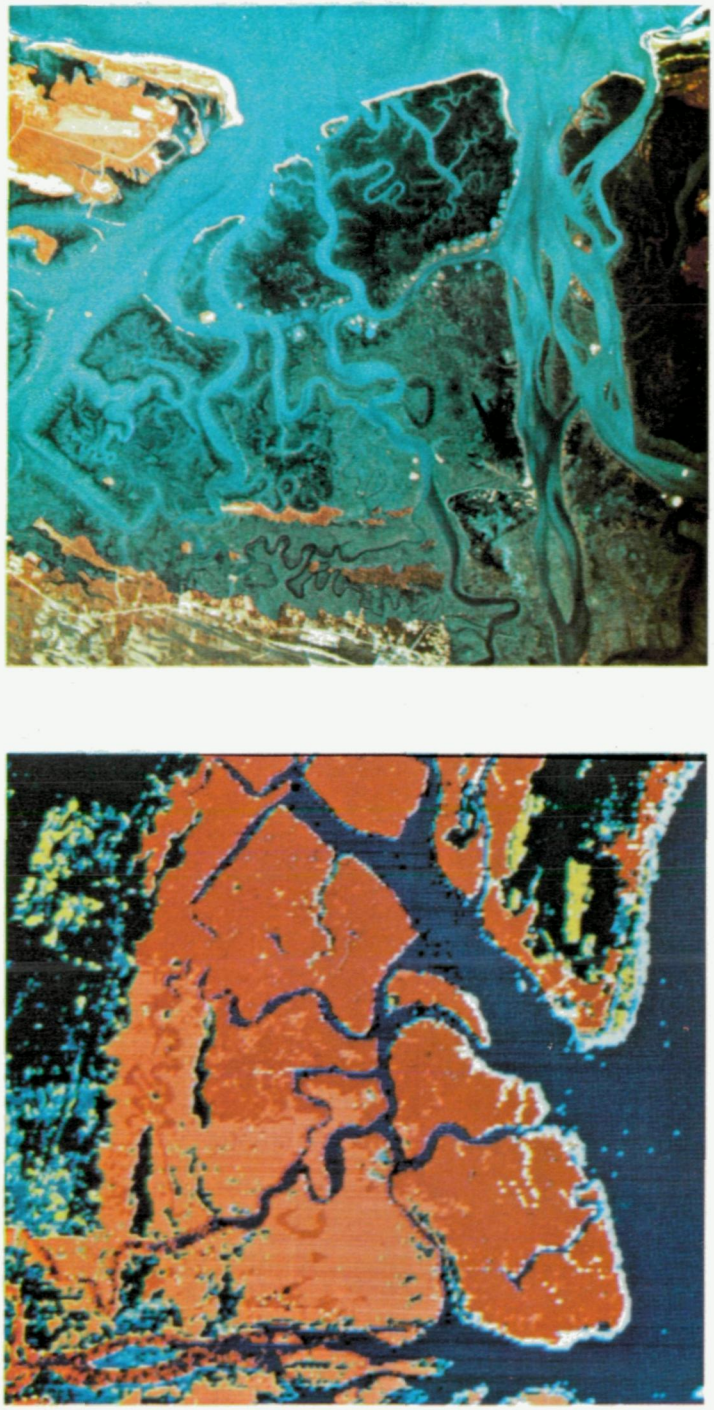
LANDSAT unclassified display of the Savannah area. It was from a video display of this tape that the following figure was classified.

Figure 2



LANDSAT classified tape of the Savannah area. These classifications were derived from training samples obtained from the unclassified display tape.

Figure 3



A comparison of a color infrared highflight photograph (TOP) and a classified LANDSAT tape (BOTTOM) both taken on October 26, 1973. The city of Darien is to the west, Sapelo Island to the north, and the Altamaha River to the south.

"OHIO'S STATEWIDE LAND USE INVENTORY: AN OPERATIONAL APPROACH FOR APPLYING LANDSAT DATA TO STATE, REGIONAL AND LOCAL PLANNING PROGRAMS"

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ABSTRACT

The purpose of this paper is to provide a brief description of the programmatic, technical, user application and cost factors associated with the development of an operational, statewide land use inventory from LANDSAT data.

The expanding scope of State planning in Ohio has necessitated the development of a comprehensive statewide land use inventory. Three State of Ohio Departments have cooperatively undertaken the development of such an inventory through the processing of LANDSAT data. LANDSAT MSS data are subjected to geometrical and categorical processing to produce map files for each of the 200 fifteen (15) minute quads covering Ohio. LANDSAT computer compatible tapes will be rescanned to produce inventory tapes which identify eight (8) Level I land use categories and a variety of Level II categories. The inventory tapes will then be processed through a series of ten (10) software programs developed by the State of Ohio. The net result will be a computerized inventory which can be displayed in map or tabular form for various geographic units, at a variety of scales and for selected categories of usage. The computerized inventory data files will be applied to technical programs developed by the various state agencies. The output of these programs will be used in State, regional and local planning programs. The entire project will be completed at a lower cost than previous statewide inventories.

INTRODUCTION

The most recent statewide, comprehensive inventory of Ohio's land uses was prepared in 1965. This first statewide land use inventory was developed from the United States Geological Survey 7 1/2 minute quad sheets prepared for Ohio between 1958 and 1964. This 15 year old inventory is in fact a "generalized" summary of Ohio land uses as they existed in 1960.

The inventory was compiled county by county using manual measurement and inventory techniques. The inventory was performed by overlaying a one acre grid template on a United States Geological Survey 7 1/2 minute quad sheet. The individual county analysis would allocate the various land uses shown on the 7 1/2 minute quad sheet into 25 categories which were later aggregated into 12. All land was divided into two broad categories; urban or nonurban.

"Urban Land" was defined as land within the boundaries of municipal corporations having a population of 2,500 or more. All land outside of these municipalities was considered "nonurban". Nonurban land was allocated among eleven (11) categories. These include: manufacturing, mining and extraction, commercial, wetlands, forest woodland and agriculture, more than ten (10) residential structures per 20 acres and 5-10 residential structures per 20 acres. The first three of these "nonurban" categories were only counted if they exceeded ten (10) acres in size. Institutional, recreation, inland water bodies and wetlands had to exceed 40 acres in size before being categorized. Nonurban residential uses had to exceed a 20 acre threshold before being categorized. All uses not fitting any of these twelve (12) categories were classified by default into a large category called "cropland, pastureland and other".

The entire inventory project took nearly two (2) years to reach completion. The twelve (12) categories were displayed for the entire state on a map sheet at a scale of approximately 1:500,000. Since data had been inventoried on the basis of county boundaries, nine (9) regional maps displaying the twelve (12) categories for groups of counties were prepared at a scale of 1:250,000. In addition, a report entitled "Use of Land In Ohio" which analyzed the data and disaggregated the twelve categories into the original 25 was published as an extension of the maps.

While detailed accuracy figures are not available for the entire inventory, spot checks for specific counties have been made. A number of inaccuracies were revealed in these spot checks. County boundaries do not coincide directly with 7 1/2 minute quad sheets. Through the course of an inventory, urban uses would be accidently allocated to adjacent counties. Forest lands, wetlands, etc., appear to unnaturally follow county boundaries in certain areas of the state. Finally, the inventory portrays uses as of 1960 while in fact, input data covered a six year time frame. Thus, differences in acreage occurred for urban areas when compared with the 1960 census.

The generalized 1960 Ohio Land Use Inventory represented a major state undertaking using one of the first HUD 701 planning grants provided to the state. The motivation for this project came from a general desire for an overall picture of the state. In effect, the project was research oriented with the small scale maps representing the primary objective and product.

The expanding scope of state planning as reflected in a wide variety of new planning programs, has generated the need for an accurate, up-to-date comprehensive Ohio land use inventory. The expanding scope of state planning in Ohio is briefly illustrated by the following examples.

- The Coastal Zone Management Act which requires coastal states (including the Great Lakes) to prepare detailed management strategies for shoreland areas.

- The expanded land use requirements of the HUD 701 program which now mandate the preparation of statewide land use programs.

- The 208 Water Quality planning process which requires significant amounts of land use data as input into the determination of quality and quantity of storm water runoff and nutrient flow into water ways.

- The technical planning assistance role of state government in Ohio has focused upon the dissemination of basic planning data such as a land use inventory.

- The reclamation of strip mined lands is mandated by Ohio 1972 Strip Mine Legislation. The development of an overall strategy for reclamation of some 346,000 acres requires the availability of detailed land use data. This program will be carried out using a portion of the excise tax on the severance of Ohio minerals.

- The development of statewide land use and growth policies require a land use inventory as a framework for decision making. Pending legislation in Ohio would focus considerable attention on the revamping of Ohio's land use planning law.

- Public concern over the preservation of agricultural land, the haphazard expansion of urban areas and the misuse of Ohio's land resources have begun to generate increasing pressure for meaningful land use plans which accurately portray present and future patterns of use.

In addition to generating the need for an up-to-date statewide inventory, the changing scope of state planning in Ohio has simultaneously provided a unique motivation for its preparation. This motivation emphasizes application requirements. The inventory is primarily viewed as a necessary input to a wide variety of on-going state planning programs, current public policy decisions and land resource issues. This emphasis upon applications requires that the inventory be completed in a flexible geographic format, at a variety of scales, with detailed as well as broad categories, and in a machine processing system which permits high speed, special purpose access to a variety of users.

These somewhat harsh constraints on the characteristics of the inventory, combined with the wide variety of potential applications have brought together the financial and technical resources of three State of Ohio Departments: the Department of Economic and Community Development, the Ohio Environmental Protection Agency and the Ohio Department of Natural Resources. These three Departments, in conjunction with NASA and Bendix Aerospace Division are cooperatively undertaking the processing of LANDSAT imagery into the required statewide land use inventory. Joint sponsorship of the inventory project represents an economical approach which eliminates duplication of effort and establishes a consistent, uniform data base utilized by the planning programs within the respective agencies.

GENERATION OF DIGITAL LAND-USE MAP FILES FROM LANDSAT DATA

The Ohio Land Use Inventory is being developed through the computer processing of 12 LANDSAT scenes. LANDSAT data, provided in the form of computer compatible tapes (CCTs), are transformed into digitally coded inventory files with each file representing the land-use within an area covered by a 15 minute quad map. A data sample, the smallest element within the file, has a north-south grid orientation, covers a ground area of 50 meters, and is coded to identify the land-use within the sample. Over 200 files based on the 15 minute quads, are being established to cover the States 44,222 square mile area.

The LANDSAT Multi Spectral Scanner (MSS) data are subjected to geometrical and categorical processing to produce the desired map files. Geometrical processing (1) establishes an earth to LANDSAT coordinate transformation, (2) develops a LANDSAT data file of a specified map area, (3) rotates the orientation of the data to north-south, (4) removes the skew in the data due to earth's rotation, and (5) resamples the data to a desired size. Categorical processing transforms the LANDSAT data samples into digital codes which identify the land-use within the sample.

The geometrical and categorical processing steps are carried out at the Bendix Data Center. The major elements of this system include: a Bendix Datagrid Digitizer System 100 for digitizing graphical data and a Bendix Multispectral-Data Analysis System (M-DAS) for the analysis of LANDSAT "computer-compatible tapes" (CCTs). M-DAS is the result of an evolutionary program initiated by Bendix in 1967 and is dedicated to the processing of remote sensing data (Johnson, 1974).

The nucleus of M-DAS is a Digital Equipment Corporation PDP-11/35 computer with 28K words of core memory, a 1.5M-word disc pack, two nine-track 800 bit-per-inch (bpi) tape transports, and a DECwriter unit. Other units are an Ampex FR-2000 14-track tape recorder, a bit synchronizer and tape deskew drawers which can reproduce up to 13 tape channels of multispectral data from high-density tape recordings, a high-speed hard-wired special-purpose computer for processing multispectral data, a 9 1/2 in. drum recorder for recording imagery on film, and a color moving-window computer-refreshed display.

The geometrical processing of LANDSAT data usually precedes the categorical processing so that processing algorithms that improve both the spatial and radiometric (spectral) resolution may be used. Additonally, displaying geometrically corrected LANDSAT data on M-DAS in the north-south orientation facilitates location and identification of training areas needed for categorization.

LANDSAT data corresponding to a specific base map is edited from the LANDSAT CCTs, and rescanned to produce data samples of a specified orientation. An earth to LANDSAT coordinate transformation is used to locate the desired area to be mapped within the LANDSAT data, and to establish the location and direction of the vector (line) used to rescan the data. The first step in developing this transformation is to digitize carefully selected ground control points (GCPs) from a map. The criteria for selecting these GCPs is that they can be easily and accurately identified on LANDSAT imagery. The second step consists of coverting the latitude and longitude of these GCPs to LANDSAT coordinates by using a theoretical transformation derived from known and assumed spacecraft parameters including: heading, scan rate, altitude, and a knowledge of earth rotation parameters. The LANDSAT coordinates and transformation matrices thus

obtained are approximate, based on the use of the nominal spacecraft parameters. This transformation matrix is used on M-DAS to produce the approximate LANDSAT coordinates and to display the area on the TV monitor. Positional errors of the GCPs identified by the operator are noted and designated by a cursor to the computer, which uses the error measurement to derive an improved set of coefficients for the transformation matrix. This procedure is repeated on additional GCPs until the desired geometric accuracy is achieved. This rapid interactive procedure is essential for producing a transformation matrix that provides an accurate transformation of earth to LANDSAT coordinates.

Once the earth to LANDSAT transformation is developed, LANDSAT data corresponding to a specific base map is edited and scanned in a west to east direction. While the data is being scanned it is resampled to produce the desired cell size. For the Ohio inventory a cell of 50 by 50 meters is being produced. The resampling methods available at Bendix range from the nearest neighbor to various popular interpolation rules such as bilinear, cubic spline and four point LaGrangian. Bendix has recently developed a discrete two dimensional deconvolution procedure which significantly improves both the radiometric and spatial resolution of LANDSAT data.

LANDSAT MSS data in either the geometrically corrected or raw data form is transformed into the interpreted land-use files by categorical processing. These categorization techniques (Dye, 1974, 1975; Rogers 1975) have been under continuous development at Bendix for the past 8 to 10 years, primarily using aircraft multispectral scanner data. More recently, LANDSAT MSS and Skylab/EREP-S192 data have been used.

The first step in categorical processing is to locate and designate to the computer a number of LANDSAT picture elements or "pixels" that best typify the land-water categories of interest, termed the "training areas". These areas of known characteristics are being established from aerial photographs and ground survey data, and are located on the LANDSAT CCTs by viewing the taped data on the M-DAS TV monitor. The coordinates of the training areas are designated to the computer by placing a cursor over the desired areas and assigning a training area designation, category code, and color code. Several training areas, typically 20 to 50 pixels in size, are picked for each category. On the raw data tapes a pixel corresponds to a ground coverage of 57 x 79 m. On the rescanned tape this becomes 50 x 50 m. The color code assigned to the training areas is later used in playback of the tapes when the computer-categorized data are displayed in the designated colors.

The LANDSAT spectral measurements within the training area boundaries are edited by the computer from the CCT and processed to obtain a numerical descriptor (computer-processing coefficients) to represent the spectral characteristics of each target category. The descriptors (Dye, 1974) include the mean signal and standard deviation for each LANDSAT band and the covariance matrix taken about the mean. The descriptors are used to generate a set of processing coefficients for each category. In automatic-category processing, the coefficients are used by the computer to form a linear combination of the LANDSAT measurements to produce a variable whose amplitude is associated with the probability of the unknown measurement being from the target sought. In category processing, the probability of a LANDSAT pixel arising from each one of the different target categories of interest is computed for each pixel and a decision, based on these computations, is reached. If all the probabilities are below a threshold level specified by the operator, the computer will decide that the category viewed is unknown (uncategorized).

Before producing categorized data for large areas, a number of tests are applied to evaluate the computer's ability to perform the desired interpretation. These tests include generating categorization-accuracy tables and viewing the processed imagery on the M-DAS TV monitor. Selection of training areas, generation of accuracy tables, and evaluation of processing results are iterative operations displayed through the use of computer printouts and the TV monitor.

The eight Level I land-use categories underlined below will be established for each of the LANDSAT scenes. Additional Level II categories will be established whenever possible. Experience has shown that; water can usually be subdivided into deep clear, shallow, and turbid; cropland into specific crop types; forest land into density related categories; barren land into sand, bare exposed rock, strip mines, etc. These additional categories will be established to the degree possible within each LANDSAT scene.

Ohio Land Use Inventory Categories

- Urban. Most dense industrial and commerical areas, major roadways, and high density residential areas. Vegetation coverage 0 to 35%.
- Suburban. Second most dense industrial and commercial areas. Includes medium to low density residential, public services, and isolated shopping centers. Vegetation coverage 30 to 80%.
- Agricultural Land. Cropland, pastureland, orchards, groves, vineyards, nurseries, and ornamental horticultural areas.
- Rangeland (Untended grass). Herbaceous range, shrub-brushland range, and mixed.
- Forest Land. Deciduous, evergreen, and mixed.
- Water. Streams, canals, lakes, reservoirs, bays, and estuaries.
- Wetland. Forest and nonforested.
- Barren Land. Beaches, strip mines, quarries, bare exposed rock, and gravel pits.

These categories correspond with the United States Geological Survey Land Use and Land Cover Classification System for Use with Remote Sensor Data. When satisfied with the categorization accuracy achieved on the land-water categories, the processing coefficients are placed into the computer disk file and used to process that portion of the LANDSAT CCTs covering the area of interest. This step in the categorization process results in new or categorized CCTs, where each LANDSAT pixel is represented by a code designating the land-water categories.

CONVERSION OF RESCANNED LANDSAT TAPES INTO AN OPERATIONAL INVENTORY STORAGE AND MANIPULATION SYSTEM

The complete set of rescanned inventoried tapes produced by Bendix will be reformated to conform to the automated georeferencing system (OCAP) developed by the Ohio Department of Natural Resources. OCAP is a set of eleven (11) programs written in PL/1 (Optimizer). The program library resides in the Ohio State Data Center which uses two IBM 370/158's with VS2 operating under ASP Version 3. Each IBM 370/158 has 2 megabytes of real storage. The OCAP programs require a minimum of 128K of virtual storage and operate typically in the range of 192-320K (virtual) depending on the size of the geographical area under study. The largest study areas to date have been complete counties (approximately 350,000 acres) with the analysis done at a resolution of approximately 1 acre. The rescanned inventory tapes are organized as a grid system where each grid represents a geographical area of fixed size. To conserve storage, the OCAP file structure records only changes in geographical information along strips of land of given width. Once the rescanned inventory tapes are in the OCAP format they can be used in any of the functions described below.

1. extensive file editing
2. file updating
3. scaling of geographical areas
4. merging of study areas
5. extraction of study areas
6. mapping of geographical variables
7. capability analysis (weighted linear model of geographical variables)
8. map overlays
9. searching of geographical attributes
10. miscellaneous file manipulation

For the purpose of the Ohio Land Use Inventory data files will be set up by OCAP, for the following geographic regions:

- State of Ohio
- 807 7 1/2 minute USGS quadrangles covering the state
- 88 counties at a scale of 1:620,500
- townships within each county
- selected municipalities

The OCAP software provides the State with a great deal of flexibility in using the inventory data. Base maps at a variety of scales can be easily established. Various geographic areas such as, groups of counties or townships and watersheds can be pulled out of the inventory files. Further, selected categories of land use may be extracted for special purpose study. This last capability makes it possible for the user to select and combine the level I and II categories generated for each LANDSAT scene. Thus, when examining the southwest portion of Ohio (Cincinnati, Dayton, etc.) it may be desirable to view three urban levels based upon density. For the northwest area of the state, the user may wish to examine only the cropland and rangeland levels. The ability to extract various combinations of land use categories has made it possible for the State to avoid establishing a fixed list of categories and in fact different categories will be established for different LANDSAT scenes.

The inventory can be presented in either tabular or computer line printer map form. Tabular data indicates a breakdown of acreage and its relative percentage, by land use category, in a selected geographic area. The tabular data will be compiled in a State Land Use Directory which will be distributed to state, regional and local planners in Ohio.

A MARK IV file management system is being generated to maintain an organized framework for the several hundred files that will be produced. The MARK IV file will be used to efficiently process requests for computer maps and/or tabular summaries for any geographical area in Ohio. Each of the state agencies can access the inventory directly from the State Data Center.

USER APPLICATIONS

In addition to investing considerable state financial resources (approximately $100,000) into the preparation of the land use inventory Ohio has moved to develop related technical programs which can directly harness and manipulate the inventory data for a wide range of state, regional and local planning needs.

Chief among these is the Ohio Department of Natural Resources's OCAP which in addition to the software package described above assembles various mapped inventories of an area's natural resources, such as soils, ground water, and bedrock, into a computerized mapping and analysis system that aids local officials in their planning activities. In it, the implications each of the resources has for future land use development are determined. These are then used to program the OCAP system to consider the ability of the area to undergo development in light of the support or limitations presented by the resource base. Land use inventory data can be directly used by the OCAP system in such analyses. Not only will the information indicate where intensive development has already taken place and where there is open land suitable for future expansion, but it will also make possible the determination of special areas, such as prime agricultural land and productive wildlife habitat, and the calculation of certain environmental measures, such as erosion potential.

Land capability analysis makes use of the best available scientific inventories in order to produce an end product that is understandable to the nonscientist. Much of the resource information necessary for analyses around the state has already been gathered, but its technical nature often prevents its use by decision makers. The OCAP system has been designed to make the translation to the everyday language used by local officials and planners. Experience has shown that most often it is the type of information being assembled in the land use inventory that is lacking and which must be gathered by the time consuming processes of aerial photo interpretation and field surveys.

The first countywide land capability analysis was performed for Lake County, where development pressures from nearby Cleveland have made it one of Ohio's fastest growing areas. Maps of the county's soils, slope, geology, vegetation, land use, watersheds, surface water, and elevation were computerized for use in the analysis. The OCAP system was programmed to produce maps showing where difficulties would be encountered during development activities, such as clearing and grading, excavation, and foundation building. It also analyzed all the resource data to indicate the best areas for various uses such as residential, commercial, agricultural, and recreational.

The computerized data base allows subsequent development of analyses for other applications as the need arises. For example the identification of areas suitable for land disposal of solid waste was developed on request after the Lake County base had been completed.

Projects are underway to use land capability analysis as an aid in virtually all of the new planning programs in the state, such as 208 water quality planning, the Coastal Zone Management Program and agricultural land preservation. The land use inventory data will be a major resource input to accomplishing these programs in a timely and effective fashion.

The Ohio Department of Economic and Community Development, in cooperation with Battelle Memorial Institute, is developing a Growth Allocation Model which will use the inventory data as a basic input for simulating the spatial, economic and environmental impacts associated with growth and development decisions. This allocation model will have several interesting attributes.

- It will utilize the land use inventory as a basic data file which provides the foundation for allocating new land uses.
- It will incorporate proven demographic, economic and environmental impact models which have been developed as components of the Department's planning program.
- The allocation model will be user oriented and can be applied to State and local planning programs throughout Ohio.

The Ohio Growth Allocation Model (OGAM), presently in the early stages of development will consist of two major components. The impact assessment component is a powerful simulation tool that may be used to identify the economic, demographic and environmental impacts resulting from growth and development decisions. The spatial allocation component describes the land use attributes of selected geographic areas and can be used to simulate spatial conditions at particular points in time as well as their change over time.

The spatial allocation component of OGAM uses a montecarlo probability surface for allocating additional population resulting from growth and development decisions. The probability surface is based upon the land use inventory for surface features, on the impact assessment component for economic and demographic features and on additional data files for physical features. OGAM will be primarily used to define the spatial location of land uses resulting from growth and development decisions. The spatial allocation procedure includes; the definition of policies which are constraints to development, an analysis of economic, environmental and social characteristics of the geographic area and criteria for analyzing the compatibility between adjacent land uses.

The compatability analysis describes the way in which adjacent land uses reinforce desired economic, environmental and social qualities of the natural and man-made environment. The purpose of the analysis is to assess the interrelationships among combinations of land uses. The analysis is done in three parts; economic compatibility is based upon the change in land values resulting from the spatial impacts, social compatibility is based upon acess to community services, and environmental compatibility is based upon the externalities resulting from the spatial pattern.

The land use inventory serves as a basic data input to OGAM. Inventory data provides the initial basis for developing the probability surface used to allocate the spatial impacts of growth and development decisions. Further, inventory data provides the beginning input for the compatibility analysis. While more detailed land use information is required to successfully complete the analysis, the inventory data can be used as a framework for adding detail.

Without the comprehensive statewide inventory developed from LANDSAT data, the spatial allocation model could only be calibrated on the basis of manual surveys conducted at great cost. With the completion of OGAM, the State will have a powerful planning tool which can be used to simulate and analyze the spatial impacts of key growth and development decisions.

The need for up-to-date information on land use, by watershed is crucial to the implementation of many water quality programs of the Ohio Environmental Protection Agency, especially as it relates to the question of non-point source pollution.

While many factors influence water quality, a dominating one is the use of land adjacent to surrounding lakes, rivers and drainage areas. During periods of rain or thaw, these areas discharge sediment and nutrients directly to the water bodies by means of surface runoff or storm drainage. Each land use category has its own special characteristic (EPA-1430, 1973) which is important in the calculation of the quantity and quality of storm-water runoff. For example, fertilized lawns (tended grass) and paved streets discharge more nutrients, especially phosphorus, than do rangeland (untended grass) and forested land. Cropland is often tilled in the spring when rainfall is heaviest and absorbs much of the water, but erosion in the form of sediments, which includes pesticides and fertilizer, are washed into nearby streams. This differs from what happens in a center city area where virtually all of the ground is covered by pavement and buildings and little or none of the water is absorbed into the earth. Instead, the water flows rapidly into storm sewers, carrying with it dirt from streets and buildings. To establish sediment and nutrient flows from the drainage areas into the waterways, accurate information on drainage area land use is essential.

Land use information presently available to planning agencies is not adequate for water quality planning purposes. The OEPA intends to use the output of the Ohio Land Use Inventory in two (2) ways. For those water quality programs presently being undertaken by regional agencies (Section 208 Waste Treatment Management Planning) the OEPA will provide uniform information on land use in a format useable for these projects. In addition, the State's overall role in water quality planning will be enhanced by the availability of the uniform data base which will be applied in phase II processing of Section 303 basin plans and in facility planning areas and environmental evaluation assessments within Section 201 construction grants.

COST COMPARISON

Completion of the entire inventory is a 9-12 month project. It's total cost is approximately $171,000. The generalized 1960 inventory cost $191,000 in 1965. The $191,000 cost is roughly equivalent to $310,000 in 1975 dollars.

CONCLUSION

The Ohio land use inventory is a beginning step. As it is completed, it will undergo accuracy and verification tests. Test sites will be randomly selected from the inventory and compared with available ground truth information. Further, the inventory will undergo continuous and varied user evaluations as it is applied to state, regional and local planning programs. The combination of random accuracy tests and user assessments will be used as input into inventory update projects.

The availability of an up-to-date, flexible statewide inventory of Ohio land uses will have significant benefits to state, regional and local planners in Ohio. These benefits include:

- The provision of a consistent data base used simultaneously by various levels of planning.
- The provision of basic data input into a number of planning programs requiring land use information.
- Encouraging the development of more sophisticated planning analysis tools which will improve the quality of public policy decisions.
- The provision of a basic planning tool - a land use inventory - which can be routinely updated at reasonable cost.

The inventory can be updated for any selected geographical configuration. For example, an update of the five county region surrounding the Cincinnati SMSA could be performed for approximately $10-20,000. On this basis, those regions of the State experiencing rapid change could be updated as frequently as necessary. More stable regions could be delayed until necessary. The timing for the update depends upon a number of factors, including data availability, funds and user needs. It is tentatively planned to request update funds in the next biennial budget cycle which begins in July of 1977 and ends in July of 1979. As the technology improves, it will be possible to periodically update and improve the coverage, accuracy and usefulness of the inventory.

These benefits represent substantial steps forward in improving the quality of planning programs in Ohio. The cost of the inventory, spread over the budgets of three state agencies is far outstripped by these benefits and the resulting improvements in Ohio's planning quality.

REFERENCES

Ohio Department of Development, Division of Planning, "Use of Land In Ohio: Report of the Land Use Survey and Analysis," December, 1967.

Dye, R. H., "Multivariate Categorical Analysis," Bendix Special Report BSR 4149, 1974.

Dye, R. H. and Chen, C. S., "Divergence Analysis of Bendix Feature Extraction Classification System," Proceedings of Purdue Symposium on Machine Processing of Remotely Sensed Data, June 3-5, 1975.

Johnson, R. H., "M-DAS Multispectral Data Analysis System," Bendix Report BSR 4146B, September 1974.

Rogers, R. H. et al, "Environmental Monitoring from Spacecraft Data," Proceedings of Purdue Symposium on Machine Processing of Remotely Sensed Data, June 1975.

United States Geological Survey, "Land Use and Land Cover Classification System for Use with Remote Sensor Data."

Ohio Department of Natural Resources, Division of Planning, "The Wolf Creek Project," 1974.

Ohio Department of Natural Resources, Division of Planning, "Land Capability Analysis: County Report Number 1, Lake County," 1974.

ARIZONA LAND USE EXPERIMENT

L-4

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ABSTRACT

The Arizona Land Use Experiment is a major experiment being conducted jointly by the State of Arizona, the National Aeronautics and Space Administration (NASA), and the U. S. Department of the Interior. The experiment concerns itself with utilizing new sources of statewide remote sensing data, taken from high-altitude aircraft and from spacecraft, and incorporating information extracted from these sources into on-going land and resources management programs in Arizona.

Statewide catographic applications of remote sensor data taken by NASA high-altitude aircraft include the development of a statewide semi-analytic control network and the production of nearly 1900 orthophotoquads (image maps) that are coincident in scale and area with the U. S. Geological Survey (USGS) 7.5 minute topographic quadrangle map series. Satellite image maps of Arizona at 1:1,000,000 and 1:500,000 scale have been produced from LANDSAT multispectral scanner imagery. These cartographic products are now being utilized for a wide variety of experimental and operational earth resources applications.

Provisions for ready access to the imagery and image interpretation equipment by the public have been made through two remote sensing data facilities in Phoenix. Film copies of high-altitude black and white metric, multispectral, and color aerial photography over the entire State of Arizona are available for public use, inspection and review at both facilities. Microfilm copies of extensive Department of the Interior aerial photography, NASA high-altitude aerial photography and worldwide earth imagery taken by the Gemini, Apollo, LANDSAT, and Skylab spacecraft are available for examination and reference in ordering hard copies at the USGS facility. Computerized geographic searches of nearly 6,000,000 frames of worldwide imagery housed in the Department of the Interior, Earth Resources Observation System data facility in Sioux Falls, South Dakota, are provided and orders for reproductions of these data are also computer processed at this facility.

Applications of the imagery, image maps, and derived information are being made in conjunction with soils and geologic mapping projects, water resources investigations, land use inventories, environmental impact studies, highway route locations and mapping, vegetation cover mapping, wildlife habitat studies, power plant siting studies, for statewide delineation of irrigation cropland, for position determination of drilling sites, as pictorial geographic bases for thematic mapping, as court exhibits, and as a ready reference to any or all areas of Arizona.

The imagery itself is a historical multispectral record of the "face" of Arizona as it recently appeared. Future changes in numerous features will be measured against this base.

INTRODUCTION

Prior to discussing details of the Arizona Land Use Experiment it is well to cover briefly certain background information which will provide a perspective as various aspects of the program are described.

Western States in particular, when faced with statewide programs, cannot avoid the basic fact that much of the land within their borders is not private or state land but includes substantial areas owned or administered by Federal agencies. Efforts toward achieving uniformity in land and resources information on a statewide basis necessitate cooperation between a host of agencies representing all levels of government.

We have found in Arizona that more often than not, the detection, collection and analysis of information by agency A stops at or near a physical boundary. Thus, land on the "other side of the fence" is measured or inventoried by agency B using another system. In many remote areas of Arizona the basic information has never been inventoried.

Efforts on the part of agencies to place project information in a broader more encompassing information system have been rare. An illustration of this point is made by considering environmental impact studies. Millions of dollars have been spent in this country on environmental impact studies without concern for standardizing the basic data collected and compiled in these studies to make it available to others who will need this same information for other purposes in the future.

The responsibility to originate a system into which basic factual information concerning a broad geographic area, i.e., a state, could be continuously input after it has been gathered for project purposes is as yet beyond the responsibility of any one agency. Such a system, accessible by both public and private users is of prime importance at this time in our history when we are confronted with the vital necessity to more wisely use our previously "unlimited" resources--whether these be related to water, energy, food production, recreation or the land upon which to establish our homes.

BACKGROUND

Arizona's wide variety of climatic conditions, geologic formations, vegetative cover and land-use patterns together with the greatest annual mean total hours of sunshine received by any state make Arizona a natural laboratory to test and evaluate remote sensor data acquired from space and high-altitude aircraft. In 1970, the U. S. Geological Survey (USGS), at the request of the National Aeronautics and Space Administration (NASA), established the Arizona Regional Ecological Test Site (ARETS) to consolidate research efforts and to test and evaluate applications of remote sensor data to earth resources and environmental problems in Arizona.

In January 1972 NASA RB-57 aircraft acquired high-altitude metric and multispectral aerial photography of 33,000 square miles (85,000 square kilometres) of southeastern Arizona in support of the ARETS project. Through the ARETS project, local, State and Federal agencies for the first time had direct access to high-altitude and space imagery of Arizona. Potential applications of the high-altitude photography were quickly recognized by many State and Federal agencies having responsibility for the management of Arizona's land and resources.

ARIZONA LAND OWNERSHIP

To understand the needs of the State and Federal agencies, responsible for management of Arizona's resources, it is instructive to examine the distribution of land ownership. Approximately 71 percent of Arizona is controlled, owned, or managed by the Federal government. Included in this amount are 19 Indian reservations, seven National forests, and 18 National monuments. Over 13 percent of Arizona is owned by the State and about 16 percent of the land is privately owned. Although only 29 percent of Arizona is State and private land, these lands are scattered throughout Arizona's nearly 114,000 square miles (300,000 square kilometres).

The widely scattered distribution of land ownership, together with a very rapid population growth and resultant land use changes, necessitates the acquisition of timely and accurate land use information for use by State and Federal land and resources management agencies. According to the Bureau of the Census, Arizona's resident population increased an estimated 21.4 percent between 1970 and 1974. Thus, Arizona is experiencing the most rapid population growth in the nation.

CONCEPT OF PROGRAM

The interest in developing useful applications of remote sensor data in Arizona was considerably deeper than just remote sensing technology. There was also a great need to "pool" information related to land in a common information system. As a means of accomplishing this information exchange between existing agencies, leadership from the Governor's Office has included the formation of the Arizona Resources Information System (ARIS), the appointment of a Policy Advisory Committee for the Arizona Resources Information System, and the appointment of a Project Director. The Policy Advisory Committee consists of the heads of nine State Agencies, plus representatives of the Governor's Office, the University of Arizona, the U. S. Department of the Interior, and the Project Director for Arizona Resources Information System. A Working Committee consisting of persons representing each of the named agencies and interested additional State agencies has been formed to carry out the necessary coordination in the development of the Arizona Resources Information System.

As further contacts were made with the National Aeronautics and Space Administration and the Department of the Interior, it became apparent that Arizona indeed had a high interest in the application of remote sensing to State government. This interest extended from the Governor's Office into virtually every State agency concerned with land. It then became desirable to formulate a unique statewide experiment to provide a basis for incorporating space and aircraft remote sensor data sources into on-going State and Federal land and resources management programs. This concept was further refined and is now the subject of a joint effort by National Aeronautics and Space Administration, The Department of the Interior, and the State of Arizona known as "The Arizona Land Use Experiment."

GOALS AND OBJECTIVES

The Arizona Land Use Experiment (ALUE) is a major experiment being conducted jointly by the State of Arizona, the National Aeronautics and Space Administration (NASA) and the U. S. Department of the Interior. The experiment concerns itself with utilizing new sources of statewide remote sensor data, taken from high-altitude aircraft and from spacecraft, and incorporating information extracted

from these sources into on-going land and source management programs in Arizona. The objectives of the experiment are:

1. Acquire high-altitude photography for a cartographic and thematic data base of the State of Arizona for experimental analyses by State agencies.

2. Reduce, analyze and annotate these data for comprehensive land use analyses that are directly related to management responsibilities of the State of Arizona and of the Department of the Interior within Arizona.

3. Incorporate the land use information into on-going and new State agency programs.

4. Document the social and economic benefits obtained through the use of these data sources.

5. Prepare a manual that can be used by other states in applying these remote sensing methods to the solution of their management problems.

6. Provide a plan for future requirements for updating land use information using data acquired from spacecraft, high-altitude aircraft, low-altitude aircraft, and ground surveys.

Early goals of the ALUE experiment consist of the acquisition of base aerial photography of Arizona, the production of orthophotoquads at a scale of 1:24,000, the development of a land use/land cover classification system compatible with the system being developed by the Department of the Interior, the selection of a series of map scales needed to display base information, the provision for training in utilization of remote sensing techniques for operational personnel, and the application of remote sensor data to resource and land management problems. The first four goals have been accomplished and applications of remote sensor data are continuously evolving.

BUILDING A GEOGRAPHIC DATA BASE

DATA ACQUISITION

The initial objective of acquiring high-altitude photography of the entire State of Arizona has been accomplished using NASA Earth Resources Survey U-2 Aircraft flying at an altitude of 65,000 feet (20,000 metres) above sea level. The aircraft operations and camera systems used are described in a Special Flight Summary Report (FRS-393) prepared by the NASA Ames Research Center, Moffett Field, California. The following sections on camera systems and flight operations were excerpted from the NASA Flight Summary Report.

Camera Systems

The camera system employed for the ALUE flights consisted of a Wild Heerbrugg RC-10 cartographic camera fitted with a 6-inch (153.22 mm) focal length lens and four Vinten cameras fitted with 1 3/4-inch (44 mm) focal length lenses. The lenses of the RC-10 cameras were calibrated by the U. S. Geological Survey to

provide the calibration data required in the process of analytic photogrammetry. Three of the Vinten cameras were filtered to correspond to the spectral bands of the LANDSAT-1 RBV System and the fourth carried SO-242 natural color film. The camera characteristics and film/filter combinations are shown in table I.

Flight Operations

The original operational plan called for the NASA U-2 aircraft staging in Arizona to conduct the ALUE flights. However, logistical constraints prevented implementation of that plan and all ALUE flights were conducted from Moffett Field, California.

The total photographic coverage of Arizona for orthophotoquad production required 45 East-West flight lines across the state centered on each tier of 7.5 minute topographic quadrangles. Both photographic coverage and aircraft operations beyond the international border between Arizona and Mexico were prohibited. The standard flight altitude for all ALUE missions was 65,000 feet (20,000 metres) above mean sea level.

The ALUE flight operations began in May 1972. However, due to the higher priority LANDSAT-1 underflights beginning in June 1972 coupled with unfavorable weather conditions, a rapid completion of the ALUE Flights was precluded.

A sufficient amount of photographic coverage was obtained during the summer of 1972 to permit full-scale initiation of orthophotoquad production. The successful completion of the flight operations in November 1973 represents a major milestone with the Arizona Land Use Experiment. Cartographic and multispectral photographic coverage of Arizona is now available for operational and research applications.

STANDARDIZATION OF SCALES

The basic purpose of the ARIS project, to develop an information system for land and resources data, is dependent upon an accurate geographical relationship between information from diverse sources. In order to interrelate this information, we are dependent upon accurate maps upon which to project irregular outlines such as flood areas or land ownership boundaries which may follow existing ground survey lines such as section lines. It was recognized that Arizona has a limited number of maps from which to select since many areas of the State are inadequately mapped. Given such a condition, ARIS has been working to develop interest in users to adopt the standard scales which exist in order to provide a graphic map compatibility.

The transfer of information from photography or imagery to a base is a key step. Techniques for accomplishing this transfer have been developed in ARIS to meet user needs. It is extremely important to grasp the graphical relationship which exists between the imagery and the base maps. The following scales have been selected, a selection of which was based on current and future usefulness, availability, and on-going map revision programs: Scales of 1:1,000,000; 1:500,000; 1:250,000; 1:126,720 (2 miles per inch) and 1:24,000. Selected examples of map and image products at these scales are listed.

Scale 1:1,000,000

Maps or Imagery

* USGS Arizona Base Map
  USGS Index to Topographic Maps
  Standard LANDSAT Imagery
  Standard SKYLAB Imagery
  Arizona Satellite Image Map
  Energy Distribution Systems Maps (AZ Oil & Gas Conservation Commission)
  Arizona Aeronautical Chart

Scale 1:500,000

Maps or Imagery

* USGS Arizona Base Map with Contours
  USGS Arizona Satellite Image Maps
  Map--The Natural Vegetative Communities of Arizona
  Geological Map of Arizona
  General Highway Map of Arizona
  USGS Arizona Shaded Relief Map
  Standard LANDSAT Imagery Products
  Standard Skylab Imagery Products
  Well Location Maps (AZ Oil & Gas Conservation Commission)

Scale 1:250,000

Maps or Imagery

* USGS Topographic Maps (old AMS Series)
  USGS Urban Area Study Map Series
    (Experimental maps of over 10,000 square miles depicting 14 land and resources themes.)
  Well Location Maps
  County General Highway Maps
  Standard LANDSAT Imagery Products
  Standard Skylab Imagery Products

Scale 1:126,720 (2 miles per inch)

Maps or Imagery

* County General Highway Map Series (AZ Department of Transportation)
    Note: This series is the most detailed statewide coverage available (planimetric). It is used as a base map by many of local, State and Federal offices for planning and operational management.
  US Forest Service National Forest Maps
  High-Altitude Aerial Photography (Nominal scale of ALUE RC-10 statewide photography)
  Experimental Orthophotomosaics

Scale 1:24,000

Maps or Imagery

* USGS Topographic Maps 7.5 minute)
  Arizona Orthophotoquads
  Nominal Scale of Conventional Aerial Photography

* Recognized Base Maps

Agencies at all levels of government in Arizona are being urged to use the above standard wherever feasible because of the benefits to be derived from scale compatibility with other map data. Numerous agencies are responding and benefiting not only from scale compatibility but from the use of recognized base maps which are prepared and maintained by professional cartographic organizations. These agencies are now free to concern themselves with the identification and location of the themes being mapped on these cartographic bases.

Recently developed equipment such as the zoom transfer scope facilitates the use of the various scale base maps together with imagery from spacecraft or aircraft. For example, the ALUE Vinten color photography (1:400,000 nominal scale) can be enlarged to a scale of 1:12,000 by projection techniques to help identify a particular feature. This feature can then be accurately positioned on the 1:1,000,000 scale base maps of Arizona using the same Vinten photography in the zoom transfer scope.

USER APPLICATIONS ASSISTANCE

Direct public access to copies of the ALUE remote sensor data and specialized image interpretation equipment is believed essential for the development of operational applications in Arizona. Provision for ready public access to film copies of the ALUE photography is provided through the ARIS Project Office and through the EROS Applications Assistance Facility (AAF) located in Phoenix. Specialized equipment including additive color viewers, zoom transfer scopes, and stereo viewers are housed at both facilities.

The ARIS Office maintains a complete file of Arizona orthophotoquads and is the sales outlet for orthophotoquads produced from the ALUE photography. Phoenix AAF provides the public reproductions of the ALUE photography at nominal cost through the EROS Data Center (EDC) located in Sioux Falls, South Dakota.

The Phoenix AAF also houses microfilm reference copies of the extensive Department of the Interior aerial mapping photography, NASA aerial photography, and the Gemini, Apollo, Skylab, and LANDSAT space imagery that is archived at the EROS Data Center. Computerized geographic searches of this data base (nearly 6 million images of the earth's surface) and public assistance in ordering copies of these data from the EROS Data Center are provided.

Scientific personnel at the Phoenix AAF are available for assistance in applying remote sensor data to resource and environmental problems. Visitors to the Phoenix AAF, who used or purchased ALUE photography between September 1972 and September 1974, were distributed as follows: 37 percent, private and commercial; 30 percent, Federal agencies; 17 percent, educational institutions; 14 percent, State agencies; and 2 percent, local government.

ORTHOPHOTOQUADS

A primary product of the Arizona Land Use Experiment is a statewide series of 1,875 orthophotoquads that are scale and area coincident with the USGS 7.5-minute topographic map series (figure 1). Produced by the U. S. Geological Survey and financed by the State of Arizona, these orthophotoquads have been completed statewide with the exception of two areas, totaling 6,000 square miles (15,500 square kilometres), which were not covered under this program.

The first exception is the greater Phoenix area where the Department of the Interior produced a set of 49 7.5-minute orthophotoquads for the primary purpose of aiding in land use planning by Indian tribes on local Indian reservations. Second, the rugged terrain within 48 quadrangles of the Grand Canyon area prevented the production of satisfactory orthophotoquads from the ALUE RC-10 6-inch (153 mm) focal length photography. As an alternate, enlargements at a nominal scale of 1:62,500 were produced to provide stereoscopic coverage of these 48 missing quadrangle areas. These enlargements, which are approximately two diameters, can be viewed with a mirror stereoscope for interpretation although extreme differences in elevation are accommodated with difficulty.

The production of statewide orthophotoquads required field marking and aerial photography of approximately 650 geodetic control points distributed throughout Arizona (figure 2). The necessary aerial photography was acquired by Arizona Department of Transportation aircraft.

The control points were marked by large white plastic panels, measuring 54 inches (1.3 metres) wide by 50 feet (15 metres) long, that were crossed and centered on the ground station. Arizona Department of Transportation field crews placed all panels with the exception of those control points located within Wilderness Areas that were paneled by U. S. Forest Service personnel. After satisfactory aerial photography was obtained the field crews returned to remove the panels.

The Department of Defense provided helicopter support for transportation of field crews to allow rapid placement and removal of paneling of control points located on military bombing ranges in southwestern Arizona. The Mohave County Engineer's Office also furnished significant assistance in Mohave County paneling operations.

The locations of the paneled control points, imaged on the 1:36,000 scale-panel photography, were transferred to the high-altitude ALUE RC-10 photography using photogrammetric point transfer devices. This transfer of geodetic control positions allowed accurate geographic positioning and scaling of the orthophotoquads produced from ALUE photography.

The orthophotoquads provide a positionally accurate composite view of a given land area and complement existing line maps (topographic and planimetric). The orthophotoquads furnish the first positionally accurate base of areas of Arizona yet unmapped at large scales. The uses and users of Arizona orthophotoquads are many and varied. These are described in the applications section of this report.

DEVELOPMENT OF LAND USE CLASSIFICATION SYSTEM

BASIC CONSIDERATIONS

In developing a Land Use Classification System, Arizona recognized early the need to combine in one system those land use categories or more appropriately those land cover categories of barren land, water, natural vegetation, agricultural land, and urban and industrial. It was further desired to have an open ended system thus permitting a nesting of specific detailed uses within a more general classification where importance or priority dictates. For example, a sixth level item could be depicted on a Level three map without affecting the integrity of the system.

COMPATIBILITY AMONG PROPOSED SYSTEMS

An important consideration is compatibility with a Federal System due to the extensive Federal lands in Arizona. With the publication of the U. S. Geological Survey's Circular 671 in 1972 a compatibility was developed between the proposed Arizona System and that of Circular 671 at Level two. Table II represents the compatibility with the 1974 proposed revision of Circular 671.

In the development of this system the results of a NASA Research Report N71-29233 (1) were used as a point of beginning and served this purpose very well. Refinements have been made as the system has undergone development. Each category is being developed with input from people working in that discipline. For example, people experienced in and working with natural vegetation in Arizona are providing input toward the development of the natural vegetation category of land cover.

NATURAL VEGETATION

A major portion of Arizona, possibly as much as 95 percent, falls within the classification of natural vegetation in the Arizona Land Use Classification System. This includes Arizona's forests, cattle grazing land, protected areas such as National parks and vast desert areas. Much of Arizona's economy depends upon these lands, whether it be for production of timber or cattle or whether it be for the scenic value of importance to our tourist industry.

Natural vegetation is also a vital element in wildlife habitat. The Arizona Game and Fish Department, because of its responsibilities for wildlife management, has participated extensively in the development of Arizona's natural vegetation classification to the sixth level (2).

SELECTED APPLICATIONS OF REMOTE SENSOR DATA

The high-altitude aircraft photography has been used in numerous instances to provide information upon which management decisions are made. Selected examples of operational applications by governmental agencies and others are listed:

ARIZONA STATE LAND DEPARTMENT

The State Land Department began using the high-altitude photography shortly after its receipt. Parcels of State land requiring decisions on leases were studied to visualize the effect of proposed easements or lease changes. In a case involving the proposed alignment of a power line, an evaluation of the ALUE photography was the basis for a recommendation to relocate several miles of the alignment in order to preserve the integrity of land uses within the corridor originally proposed.

A system for accurately displaying distributions of State land, land characteristics, land use, resources, and ownership is under design which incorporates the orthophoto base of the State as a reference base. The orthophotoquads prepared from the ALUE pohtography provide a valuable visible reference when an agency is studying a specific area in detail. This photographic base facilitates correlation with other photography or imagery, whether it be very old photography from aircraft or new imagery from space.

ARIZONA DEPARTMENT OF TRANSPORTATION

Since the ALUE photography was first received it has been widely used in this agency. A high usage has been made in the agency's County Mapping Program to update the 1:126,720 scale planimetric County Map Series in Pima and Greenlee Counties, to conduct aerial reconnaissance studies for updating maps of the Papago Indian Reservation and to review virtually the entire state to detect changes requiring map revisions. Enlarged ALUE photography was used for field annotations and also for direct updating of detailed map enlargement areas. The orthophotoquads produced from the ALUE photography have simplified this process considerably since the county map enlargement areas are coincident in scale and cover either the north or south half of one orthophotoquad.

The orthophotoquad project combined the use of high-altitude ALUE photography, paneling of existing ground control stations, analytic photogrammetry, and orthophoto production techniques into the first project of its kind for statewide coverage (3). This project has been completed and orthophotoquads are being used in a variety of applications (4). These applications are resulting in increased usage of the 1:24,000 as a standard scale.

Personnel of Arizona Department of Transportation were directly involved in virtually all phases of the orthophotoquad project. This participation was vital to the accomplishment of the project.

Negatives of the ALUE photography are located in this agency for use in producing prints and enlargements required by State agencies. Many of the copy negatives are difficult to print or enlarge, because of their high contrast and high density.

One of the more sophisticated applications of Arizona orthophotoquads is taking place within the Arizona Department of Transportation's Accident Location, Identification and Surveillance System (ALISS). The locations of Federal, State, and local road networks are being digitized, using the Arizona State Plane Coordinate System, to assist in the study and analysis of accident locations. Most road alignments outside the metropolitan areas are being located by direct digitization from stable base copies of the Arizona orthophotoquads. Federal and local government agencies are also directly involved in this project.

In a closely related road and traffic control inventory, many counties in Arizona are producing their first county road system inventories. This represents a major undertaking since only four Arizona counties are smaller than the State of Connecticut.

ARIZONA OIL AND GAS CONSERVATION COMMISSION

The Arizona Oil and Gas Conservation Commission is using Arizona orthophotoquads, ALUE photography, and other existing photography to accurately locate wells and drilling sites. It is of primary importance to the Commission to be able to determine accurate locations of drill sites in unmapped areas of northern Arizona.

ARIZONA WATER COMMISSION

The Arizona Water Commission is making extensive use of the ALUE photography to help evaluate geologic and hydrologic conditions in areas of proposed new subdivisions. Application for new subdivisions in Arizona requires a statement of water availability that is reviewed by the Arizona Water Commission.

ARIZONA DEPARTMENT OF PUBLIC SAFETY

In order to obtain complete photo coverage of Arizona for purposes of producing orthophotoquads to the International Border, supplemental photography was taken along this border by State aircraft. The Department of Public Safety is now utilizing this photography in their activities to curb the smuggling of narcotics into the United States.

MARICOPA COUNTY ATTORNEY'S OFFICE

A special application of orthophotoquads was made in a county criminal court case in which a mosaic of orthophotoquads clearly illustrated the physical appearance and extent of the area of interest. This exhibit, although introduced by the prosecution, was also used as a reference by the defense.

PUBLIC UTILITIES

Extensive use of the ALUE photography has been made by Arizona public utility companies in connection with studies of power plant sitings and power transmission line routings. The remote sensing applications included current land use mapping, vegetation mapping, geologic mapping, and evaluation of wildlife habitat. Timely completion of certain environmental impact studies related to these projects would not have been possible without the ALUE photography.

MINING AND EXPLORATION COMPANIES

Copies of the ALUE photographic coverage of large areas of Arizona have been purchased by mining and petroleum companies for use in connection with geologic studies and mineral exploration projects. Arizona orthophotoquads are receiving extensive use in connection with these activities.

FEDERAL HIGHWAY ADMINISTRATION

The Federal Highway Administration has used a visual examination of specific bridge sites, drainage areas, and geologic formations to independently review highway project information. The analysis of ALUE photography has often provided satisfactory means of verifying the information in question and provides a synoptic view of the entire setting of the project in many cases.

U. S. SOIL CONSERVATION SERVICE

The U. S. Soil Conservation Service is using the high-altitude ALUE photography and orthophotoquads in conjunction with Arizona soil mapping projects. The resulting maps will be at the standard 1:24,000 scale overprinted on the orthophotoquad image base. Compatibility of the soil information with existing topographic maps will provide a valuable user benefit.

U. S. GEOLOGICAL SURVEY

The U. S. Geological Survey (USGS) Topographic Division field engineers have utilized the Arizona orthophotoquads in connection with on-going topographic mapping projects. The Arizona orthophotoquads are also being used in connection with the revision of existing maps.

The USGS Water Resources Division has successfully utilized the ALUE photography in connection with water resources investigations including geologic mapping, flood studies, and mapping natural vegetation and irrigated croplands. The Water Resources Division has successfully used a combination of enlargements of ALUE photography together with Arizona orthophotoquads for accurate determination of water well locations in unsurveyed areas. The distribution of irrigated croplands in selected basins has been studied using LANDSAT imagery.

U. S. BUREAU OF LAND MANAGEMENT

The Bureau of Land Management (BLM) is using Arizona orthophotoquads in connection with a wild burro census in western Arizona. The orthophotoquads are being used as a base on which to plot burro distributions as observed during low-altitude aerial reconnaissance flights. The BLM has also used NASA high-altitude aerial photography in connection with soil mapping studies, range resource inventories, archaeological investigations and recreational use studies.

U. S. BUREAU OF INDIAN AFFAIRS

The Bureau of Indian Affairs (BIA) has used Arizona orthophotoquads to update maps showing road networks, vegetation patterns, and cultural features on the San Carlos Indian Reservation. The ALUE orthophotoquads and NASA high-altitude aerial photography is being used by BIA for soils and land use mapping on the Navajo Indian Reservation in northeastern Arizona.

U. S. BUREAU OF RECLAMATION

The Bureau of Reclamation (BR) is making extensive use of the ALUE multispectral photography for vegetation mapping along the Colorado River in western Arizona. The BR is also using the ALUE multispectral high-altitude photography together with space imagery in connection with environmental studies in southwestern Arizona.

SATELLITE IMAGE MAP

The Arizona Satellite Image Map of Arizona, prepared and published by the USGS at a scale of 1:500,000, is being used at this and other scales by a variety of State agencies to portray information. The General Highway Map has been overprinted on this base (figure 3). This composite map has been overprinted with remote subdivision information by the Office of Economic Planning and Development. A series of Arizona Climatology Maps depicting weather station locations, air temperatures, amounts of precipitation, location of solar radiation stations, annual peak evaporation rates and evapotranspiration rates has been overprinted on the satellite image map published jointly by the State Climatologist and the Arizona Resources Information System.

Additional applications of the Arizona Satellite Image Base are under development or consideration by several agencies that will take advantage of the repetitive LANDSAT imagery.

OTHER SPACE APPLICATIONS

The U. S. Geological Survey, working closely with the Salt River Project, is using the LANDSAT Data Collection System to relay information on snow-water equivalent data and streamflow rates from remote ground stations in central Arizona to assist in the management and operation of reservoirs on the Salt and Verde Rivers. LANDSAT and NOAA-3 imagery are being used for mapping snow-cover distributions over the 13,000 square miles (34,000 square kilometres) of the Salt-Verde watershed located in central Arizona.

SUMMARY AND CONCLUSIONS

The Arizona Land Use Experiment is a major experiment to incorporate information extracted from remotely sensed data into on-going land and resource management programs in Arizona. Statewide high-altitude cartographic and multispectral aerial coverage of Arizona has been completed and is now available for operational and research applications.

Production of 1,875 orthophotoquads from the high-altitude photography has been completed and provides an accurate 1:24,000-scale image base of Arizona for public use and for use by governmental agencies responsible for management of Arizona land and resources.

Provision for ready public access film copies of the ALUE photography and specialized image interpretation equipment has been provided, together with assistance in applying remote sensor data to Arizona's resource and environmental problems. Copies of the ALUE photography, other NASA and Department of the Interior

aerial photography, space imagery and Arizona orthophotoquads are available to the public at a nominal cost.

Numerous applications of remote sensor data have been developed using high-altitude aircraft and space imagery in response to the needs of governmental agencies in Arizona. Additional applications are continuously evolving.

Through the joint development of applications of remote sensor data in Arizona, large-scale cooperation and coordination between all levels of government has been demonstrated. Private, commercial, and educational institutions are making significant utilization of the data and facilities provided through the Arizona Land Use Experiment.

REFERENCES

1. NASA Research Report N71-29233: The Application of High-Altitude Photography for Vegetation Resources Inventories in Southeastern Arizona. L. R. Pettinger, et al. (California University) December 31, 1970.

2. Brown, D. E., and Lowe, C. H., 1974. A digitized computer-compatible Classification for Natural and Potential Vegetation in the Southwest with Particular Reference to Arizona. Jour. Ariz. Acad. Sci., vol. 9, suppl. 2, pp. 1-11.

3. Winikka, Carl C., and Morse, Samuel A., Jr., "Orthophotoquads for Arizona Land-Use Mapping and Planning," Journal of the Surveying and Mapping Division, ASCE, vol. 100, Proc. Paper 10525, May 1974, pp. 1-6.

4. Winikka, Carl C., "A Statewide Orthophoto Base," Proceedings of Orthophoto Workshop III, American Society of Photogrammetry and Mapping, San Antonio, Texas, June 1975.

TABLE I.--ALUE CAMERA SYSTEM CHARACTERISTICS

Camera	Focal Length	Film Type	Filter	Spectral Band (nm)	Intervalo-meter (sec)
Wild Heerbrugg RC-10	6 in. (153.22 mm)	Plus-X, EK 2402	WR 12	510-700	58
Vinten	1-3/4 in. (44 mm)	Plus-X, EK 2402	Schott GG 475 + Schott BG 18	475-575	50
Vinten	1-3/4 in. (44 mm)	Plus-X, EK 2402	Schott OG 570 + Schott BG 38	580-680	50
Vinten	1-3/4 in. (44 mm)	IR Aerographic, EK 2424	Schott RG 645 + Corning 9830	690-760	50
Vinten	1-3/4 in. (44 mm)	Aerial Color, EK SO-242	None	400-700	50

TABLE II.--LAND USE CLASSIFICATION SYSTEMS

COMPATIBILITY OF ARIZONA AND U. S. DEPARTMENT OF THE INTERIOR

LAND USE CLASSIFICATION SYSTEMS

July 2, 1973

1974

ARIZONA	U.S.G.S. (Circular 671)	
100 BARREN LANDS		
110 Playas	0701	Salt Flats
120 Dune Lands	0703	Sandy Areas other than Beaches
130 Rocklands	0704	Bare exposed Rock
140 Shorelines, Beaches & Riverbanks	0702	Beaches and Mudflats
190 Undifferentiated Badlands	0706	Transitional Areas
	0707	Mixed Barren Land
200 WATER RESOURCES		
210 Bodies of Water *	0502	Lakes
	0503	Reservoirs
220 Water Courses *	0501	Streams and Canals
230 Point Sources of Water *(Natural vs. Artifical classified at 3rd level)		
240 Water Control Structures		
250 Potable Water Storage Reservoirs		
270 Snow and Ice	0901	Permanent Snowfields
	0902	Glaciers
290 Other Water Resources	0905	Other Water
	0904	Bays and Estuaries
300 NATURAL VEGETATION		
310 Tundra	0801	Shrub and Brush Tundra
	0802	Herbaceous Tundra
	0903	Bare Ground Tundra
	0804	Wet Tundra
	0805	Mixed Tundra
320 Forest*	0401	Deciduous Forest
	0402	Evergreen Forest
	0403	Mixed Forest
330 Woodland * *(Deciduous vs. Evergreen classified at 4th level)		
340 Scrubland	0302	Shrub-Brushland Range

TABLE II.--LAND USE CLASSIFICATION SYSTEMS (continued)

300 NATURAL VEGETATION (continued)	
350 Grassland	0301 Herbaceous Range
360 Desertscrub	0302 Shrub-Brushland Range
370 Marshland	0601 Forested Wetland 0602 Non-forested Wetland
	0303 Mixed Rangeland
400 AGRICULTURAL LAND	
410 Irrigated by Gravity Water* 420 Irrigated by Pumped Water* 430 Irrigated by Combination of Gravity and Pumped Waters* 440 Dry Farming* *(Crop Family--3rd level)	0201 Cropland and Pasture 0202 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
450 Livestock Facilities	0203 Confined Feeding Operations
460 Animal Specialties 470 Horticultural Specialties	0202 Orchards,Groves, Vineyards, Nurseries and Ornamental Horticultural Areas
	0204 Other Agricultural Land
500 RESIDENTIAL, INDUSTRIAL AND COMMERCIAL	
510 Residential	0101 Residential
520/530 Manufacturing	0103 Industrial
540 Transportation, Communications and Utilities	0104 Transportation, Communications and Utilities
550 Trade 560 Services	0102 Commercial and Services
570 Cultural, Entertainment and Recreational	
580 Resources Production	0705 Strip Mines, Quarries, and Gravel Pits
590 Vacant Urban Land 591 Rural Subdivided	
	0105 Industrial and Commercial Complexes
	0106 Mixed Urban & Built-up Land
	0107 Other Urban & Built-up Land

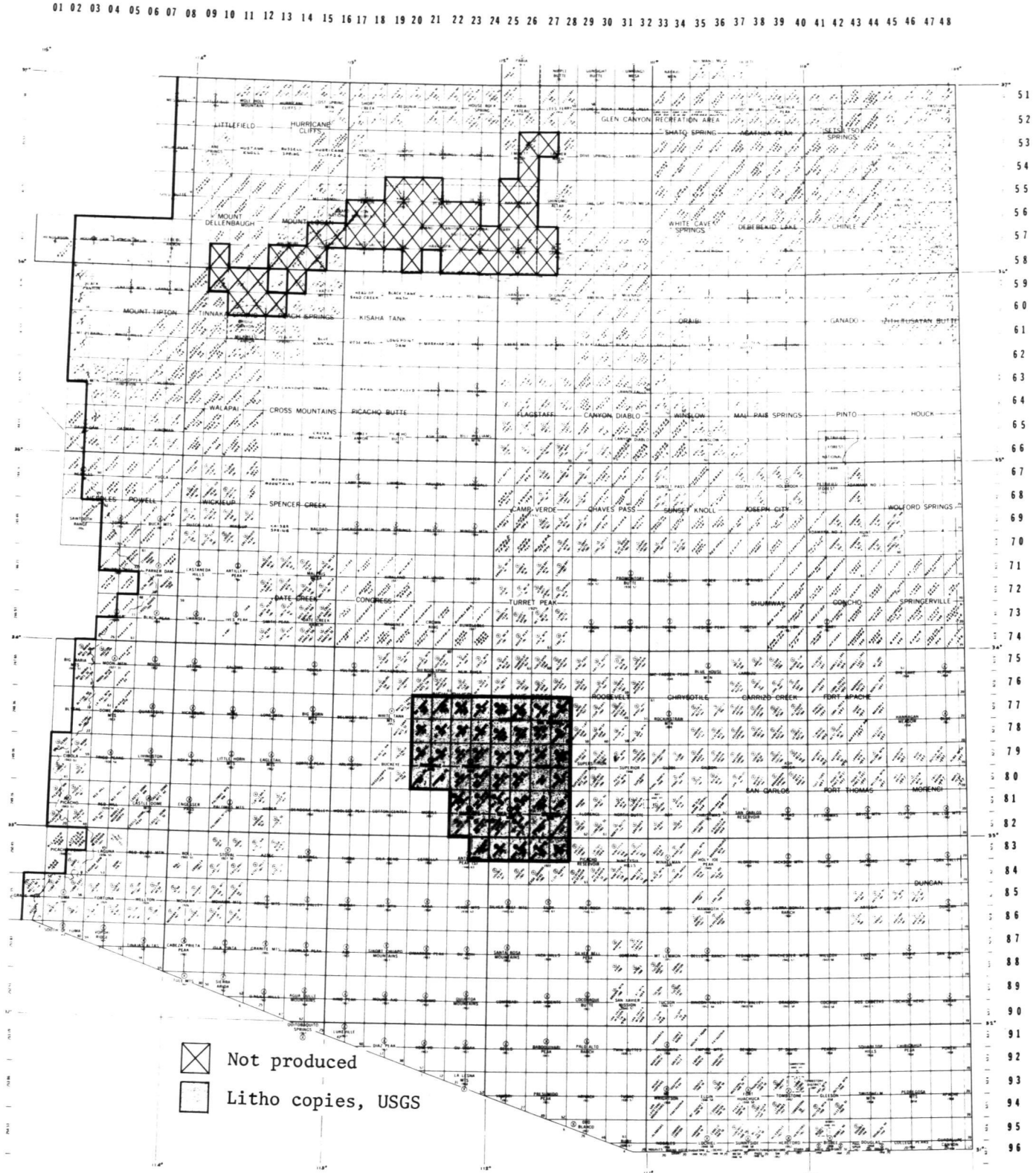


Figure 1.--Arizona Orthophotoquad Index.

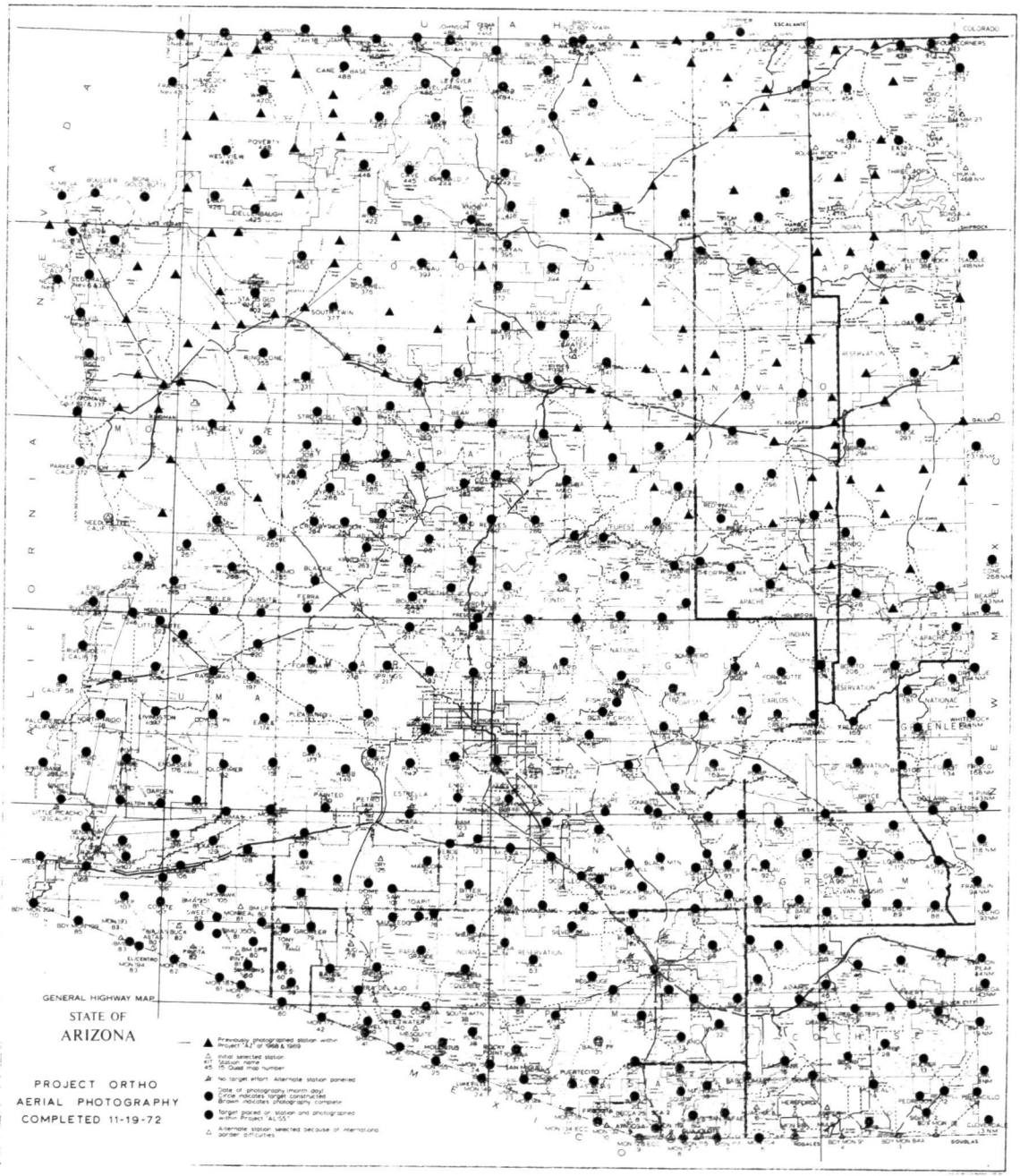


Figure 2.--Control Diagram.

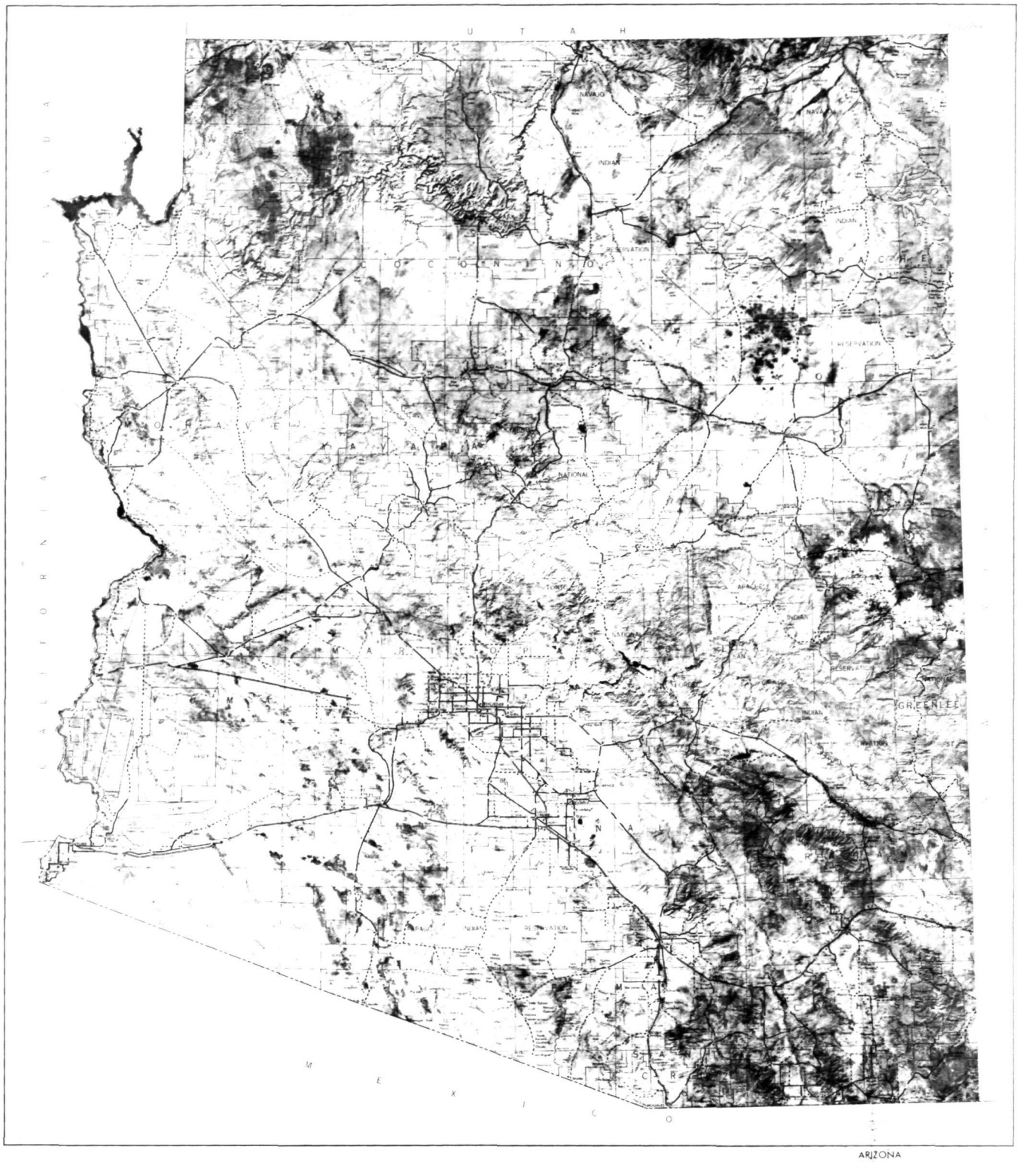


Figure 3.--Arizona Satellite Image Map with General Highway Map Overprinted.

THE DESIGN, IMPLEMENTATION, AND USE OF A STATEWIDE LAND USE INVENTORY: THE NEW YORK EXPERIENCE

Ernest E. Hardy, Cornell University, Ithaca, New York

INTRODUCTION

The New York State land use and natural resource inventory is the first statewide inventory that we know of in the present mode. When we started, we had many new tools; we had people's enthusiasm; and we had a state-level agency that was willing to support the work. The Office of Planning Services provided the support. The people with some of the new ideas included Professor Don Belcher, who was at that time the director of the Center for Air Photographic Studies, and Ron Shelton, who is on the staff of Michigan State University. I comprised the third member of the team that was involved with generating this particular project.

We saw an opportunity to try a new approach to developing an inventory of natural resources throughout the state. We had aerial photographs, computers with unusual storage capacities, and numerous available resources such as soil maps and zoning information. The ability to work with computers is definitely recognized in terms of the computer's ability to handle geographically referenced information.

When the opportunity for this project occurred, we had a request for a statewide inventory that would handle nine items of information, which were the usual ones: water, land, public land, farmland, woods, and so forth. As we got into the project and got the interest of many people incorporated into the work, the list of requested items grew to 185. We trimmed the list to about 135 items for this project. We had done other projects that had gone as high as 300 items of information for an inventory.

We found that our initial ideas were slightly naive. For example, no good geographic referencing system existed that would work economically for this type of project. We also discovered that computer programing, although initiated by Carl Stenus' group at Harvard and well underway, was not capable of handling a 50 000-square-mile area with 135 items. We also discovered that no one had given any serious thought to the basic concept necessary to undertake a wide-scale resource inventory of this type.

DESIGN AND IMPLEMENTATION

In considering the overall perspective of what an inventory was going to accomplish for us, we realized that we really wanted to generate something that, in its simplest, most ideal form, would take information from any source (clipboard or satellite); run it through any kind of a process (manual or computer), and, if done properly, produce information of use to any user. This perspective seems to be working as a fundamental concept.

This concept actually ends up with the creation of a warehouse of data from which the user combines things as he sees fit or as he sees a need in a particular case. To make this concept work, the user has to input as much unbiased information as possible. Even the soil map from this concept has acquired a built-in bias that can be a problem at a later date. I have seen very little evidence of anyone paying much attention to the idea of using only unbiased information in this system. After acquiring the information, the user then infers and interprets the information to suit particular needs and problems.

The geographic-location problem was solved rather early. We searched the number of possibilities and concluded that the cheapest, most efficient method to work with for getting a numerical system into a computer was to use the UTM grid system, which divides very economically. This method is available to large areas, such as the entire State of New York. Six digits identify the location as a kilometer; eight digits, as a hectare; ten digits, as an area about the size of a small auditorium; and twelve digits, as an area

about the size of a desk. It is a powerful, effective system; it will work cheaply in the computer program that we have; and it provides an excellent location reference approach for us.

In 1968, no computer programing was available. There were some programs that had been developed to use cards in sequence. We experimented with those programs and got up to 9000 cards. We found that getting up to 9000 cards was easy, but to get them into a sequence was difficult. The cards are gone now.

We also realized there is no single best inventory. Any user who wants information prepared for him is going to have his own ideas about data he wants. Thus, we concluded that whoever wants the information is going to be interested in getting something out of it for his personal use. The sources of information are extremely varied, and we have many different sources of information in the system. The basic source for this particular inventory was low-altitude aerial photography, but we can also use other sources. If we can geographically reference it, we can get the information into the program and go to work. About 80 percent of the information came from aerial photographs; about 15 percent came from secondary sources; and about 5 percent came from actual personal contacts with people getting specific kinds of information from their knowledge of the world around them. We can actually locate the information on the map to as small a measurement as feet. We do not pull it out of the computer page and add mode because there isn't any particular demand for it at that scale, as long as we have it available in some form.

The question of accuracy frequently occurs. There is much confusion about geographic referencing in terms of the cartographic characteristics of an inventory; however, what is even more important is the accuracy of the interpretation process itself. The grid-cell idea does provide an excellent locational accuracy level. We acquire the grid cell after we have done the curvilinear mapping so we can go to the polygon system if we want to. We do not have to restrict ourselves to either a grid or polygon system in the early stages of an inventory process.

The knowledge that there are only three good ways to measure things on a map solves many problems. A person can measure things with a line, with a dot or a point, or combine dots and points to make lines for enclosed areas. The entire process then comes down to this question: How do you handle the statistical data or the numbers that go with the lines, dots, and maps?

The classification gave us much more trouble. We depended heavily on the soils people and some of the knowledge that they had developed. We soon realized that the description of the classification unit is the most important item in the entire process. Without description, we really have very little to work on. If the description is done well, it uniquely identifies every item in the inventory. If the description is adequate and unique, then it is easy to come up with a discrete assignment for each of the items. No one item can possibly fall into two categories. If we have a unique description with discrete assignments, then it is possible to go ahead and complete a comprehensive coverage of the entire item. In the New York inventory that we did several years ago, we had a sizable matrix of materials. One-hundred items result in a matrix of 10 000, and we can extract every item in any 1 percentile that we wish. Possibly millions of different kinds of maps can be obtained from the information system. We can incorporate 25, 30, or 40 different factors simultaneously, which means the total is close to a billion.

Another factor that we did not plan on is that we have excellent sampling design possibilities once a standard system is established, especially a grid system on a statewide basis. This opens research opportunities in every other field of land use information: populations, demography, economics, and so forth. Moreover, these opportunities keep expanding as time passes.

The process that we developed has many products, such as hand-drafted maps, that we make available to the general public for a reproduction cost. The process has record books; all raw data have been maintained in depth. We can produce statistical lists on computers; we can produce computer printout maps; and we can provide information for almost any application with which a user might want to be concerned.

New York is a large state, and figure 1 is an illustration of what happens when people look at something from fifty different points of view. Various items in the inventory can be specifically identified and located. Figure 2 shows a lock in one of the major canal systems. Because the location of our delicate resource areas (fig. 3) is very well defined, we can pinpoint them very accurately and develop a very detailed analysis of them. Public service units, such as waste disposal plants (fig. 4), are easily located. A colonized pipeline (fig. 5) or anything that dissects the countryside can be represented as a linear feature. Many varieties of land use are represented in figure 6; for example, we have the only inventory of frogponds that we know of. We have contour ditches and different kinds of forest, land, housing, and transportation. We can put in flood plains and a number of these certain items at the same time. Commercial strip development goes into a separate category, whether it is a roadside market (fig. 7) or some other kind of operation. Waste disposal, whether from mining (fig. 8) or other sources (figs. 9 and 10), is very readily located. We have many recreational facilities in the form of bungalow colonies through out parts of the state (fig. 11), and each facility gets a separate type of classification among the recreational units. Figure 12 is a ski resort in the northern part of the state in the Keene Valley. The entire area can be mapped, or we can include it as woodland. Shoreline development along lakes (fig. 13) is no problem. The planners who are interested in the freshwater bodies can easily find those that have been developed. The cottages can be identified either in linear features or in point data. For recreational sites like the small marina shown in figure 14, we can provide the number of boats.

Pollution can be represented in three different ways. We can locate the point; we can locate the linear extent of it along the shoreline of a freshwater body; or we can locate it in terms of the area of the water surface that was affected as shown in figure 15. The technique for obtaining this information is manual. We use a manual drafting technique with which we can input these data for as little as $0.04 per kilometer. Figure 16 shows a comparison of LANDSAT and Skylab imagery; either can be used. We have technical developments that have allowed us to extract this information at very little cost from very wide areas and to incorporate this kind of information in a computer storage system. The raw data are stored in bookcases and are available to anyone. In approximately 3 minutes, we can explain to anyone how to find his or her particular area and work on the raw-data materials. The maps for reproduction are stored simply and economically and are reproduced at about $5 or $6 per print for outside users. Figure 17 is an example of what the map looks like on Mylar. A user can simply overlay it on a topographic map to obtain the topographical information and all the other areas needed. We can also provide the computer printout (fig. 18).

We have used a variety of input systems. The system shown in figure 19 cost us $36 000, and we could produce a map using this digital input from the computer system for approximately $255 to $260. If we used the system shown in figure 20, which is a $1.98 abacus, we could get the map cost down to $45 or $50. By using the system illustrated in figure 21, which is a $0.03 piece of plastic, we could get the map cost down to $28. We use the latter system, which is the cheapest, because it can still be done, even with the increase in wages, for less than $35 per map.

The products are made basically with curvilinear features, and then a grid system is applied over the curvilinear features. We do not apply the grids first. We have point and area maps; for example, figure 22 is an area map of land use. The topographic map behind it is the most accurate means of measurement that we have. It is not used for any other information. Figure 23 is an example of the completed map ready for reproduction.

All the map work is field checked, and we have had an accuracy level of above 94 percent on the decisionmaking process for the state as a whole. We have obtained an accuracy as high as 95, 98, and 99 percent in some areas. The transfer is eyeballed; therefore, everything has to go on the topographic map for accurate measurements. The interpretation is straightforward, using only pocket stereoscopes and pencil work. The aerial photointerpreters are encouraged to use as much backup material as they can get. From people in the field, we gather data that will be incorporated on the topographic map to broaden the accurate use and interpretation process.

A very simple problem developed when we started to revise the classification system that is illustrated in figure 24. In a recent project, the researchers requested that we increase the number of forest-cover types from 4 to about 16. The result was a very high degree of complexity throughout the whole State of New York. This one request might increase the cost of doing another statewide inventory by as much as 25 to 40 percent. Classification of major problems is even more complicated. In this classification and description, the products are actually prepared and separated; we stack them up and run them onto a number of different resource output cards.

In terms of design concepts, we have found the following 11 steps to be very important:

1. The overall design of the project in relation to its uses
2. The classification based on the needs and resources of value
3. Data acquisition
4. Geographic referencing
5. Data processing
6. Data storage
7. Data retrieval
8. Application
9. Warehousing of raw data
10. Development of a user service
11. Documentation of the entire operation

This last step includes the computer program, the techniques for doing the work, and, above all, a photographic atlas of the land uses that have been recorded at that time. Without this atlas, we do not really have a resource inventory, and if we fail to take time to create this atlas concept, it is impossible to do the work over again. Ninety percent of our thousands of applications and requests are for map overlays, whereas only 10 percent are for the computer products.

APPLICATION

The total cost of the New York State inventory, which was done from 1968-70, was $10 per square mile for 135 items, computerized and geographically recognized. We did 6300 square miles in the summer of 1974. Not including the computer phase, we were still able to do 104 items for $10 per square mile. In 1975, we made an estimate for a statewide inventory that will cost between $12 and $15 per square mile for 140 items. To get satellite information into the system through our manual output products costs about $0.04 per square kilometer for level 1 category from a 671 image.

We have encountered a few major problems. One problem is simply sustaining support. Some other states have taken an active role in developing state land use systems. Another problem is that classification theory is essentially being overlooked and is undeveloped. Cooperation among state, federal, and local agencies brings problems in most cases. A technology transfer in the form of user services is almost nonexistent throughout the country, which is the biggest flaw in the whole system if we are to make progress in the future.

In summary, the higher the degree of sophistication of a system, the fewer users there will be. In addition, the greater the number of items, the greater the need for less sophisticated means. It is impossible to put points in very short lines in this process;

yet, it is critically important in a land use inventory. Obviously, the higher levels of government will be able to use the more sophisticated systems much more easily than the lower levels.

Cartographic accuracy and interpretation accuracy are misused and misconstrued concepts. Our greatest concern should be the interpretation accuracy rather than the cartographic accuracy. The testing of an inventory is rare, and few inventories contain any clue to their accuracy level. The testing of the talent that produces the inventory is even more rare. I've never found an instance when two people doing the same part of a job were evaluated against each other.

Most of us may be overlooking many of the good products that some labor-intensive opportunities still offer for dealing with the large volume of resource information. Another point that many of us overlook is that not every land use information system is automatically transferable to other parts of the country or other parts of the world.

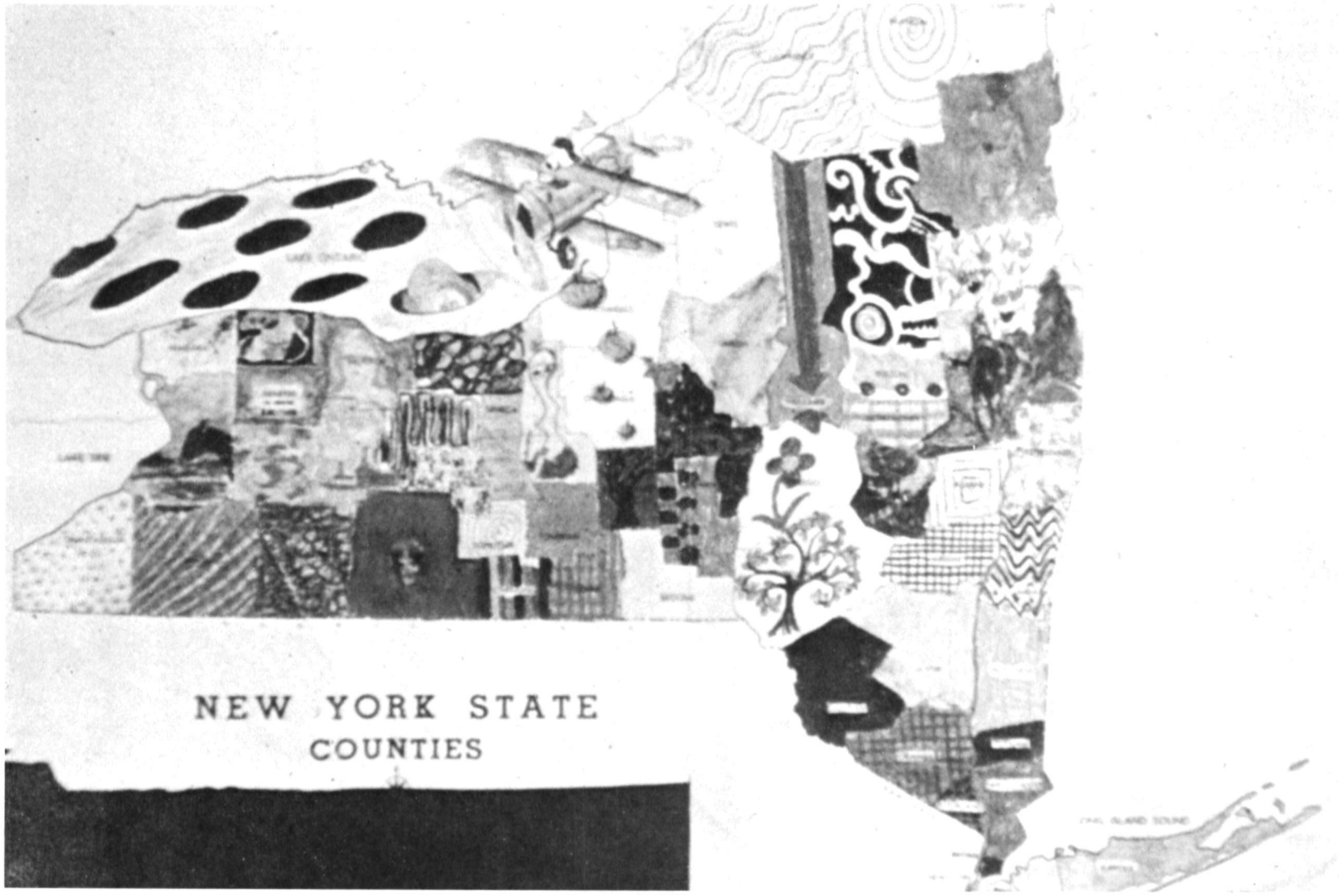


Figure 1. A divergent inventory of New York State counties.

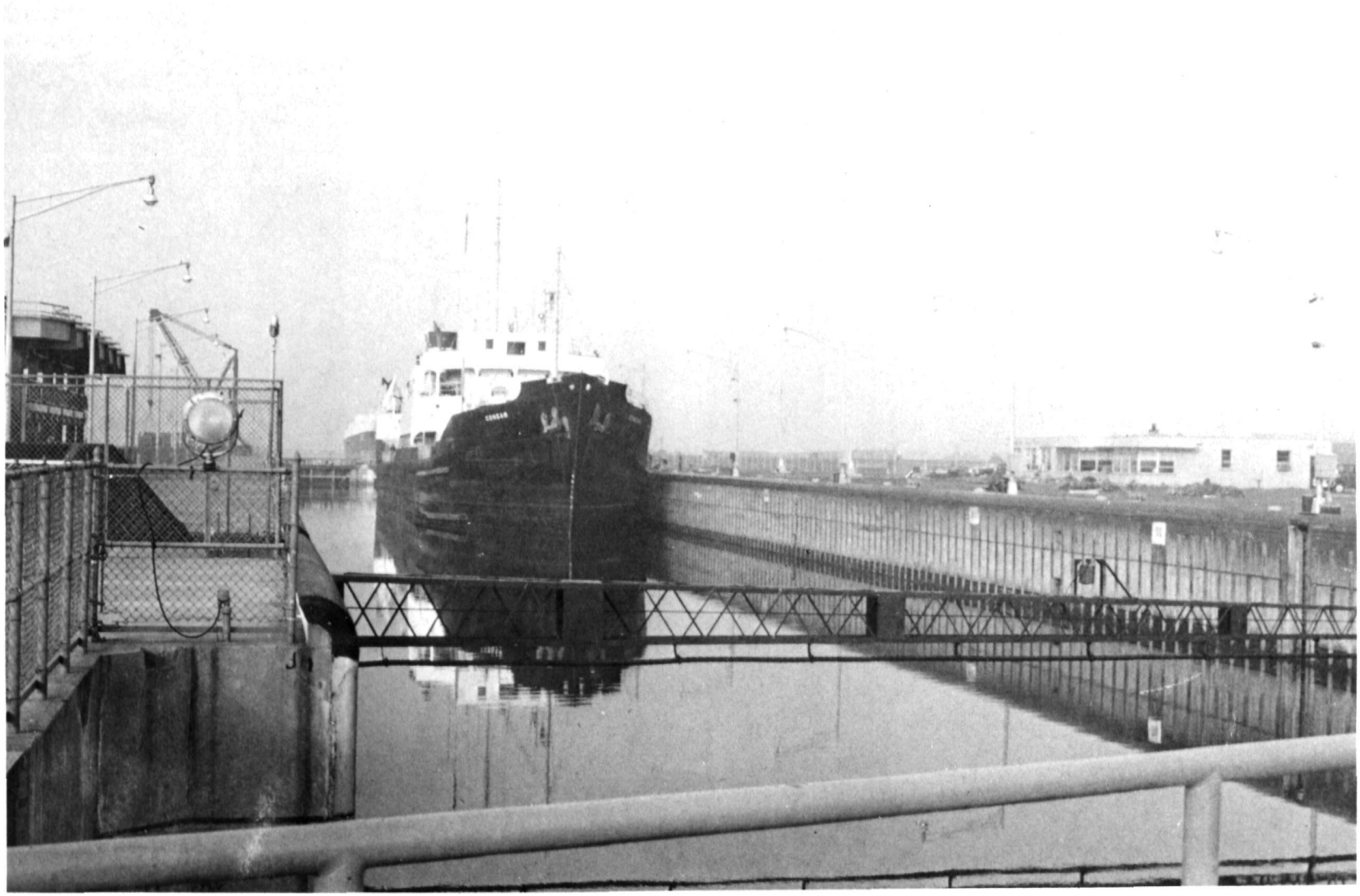


Figure 2. A lock in a major canal system.



Figure 3. A delicate resource area.



Figure 4. One kind of public service unit: a sewage plant.



Figure 5. A colonized pipeline forms a linear feature.

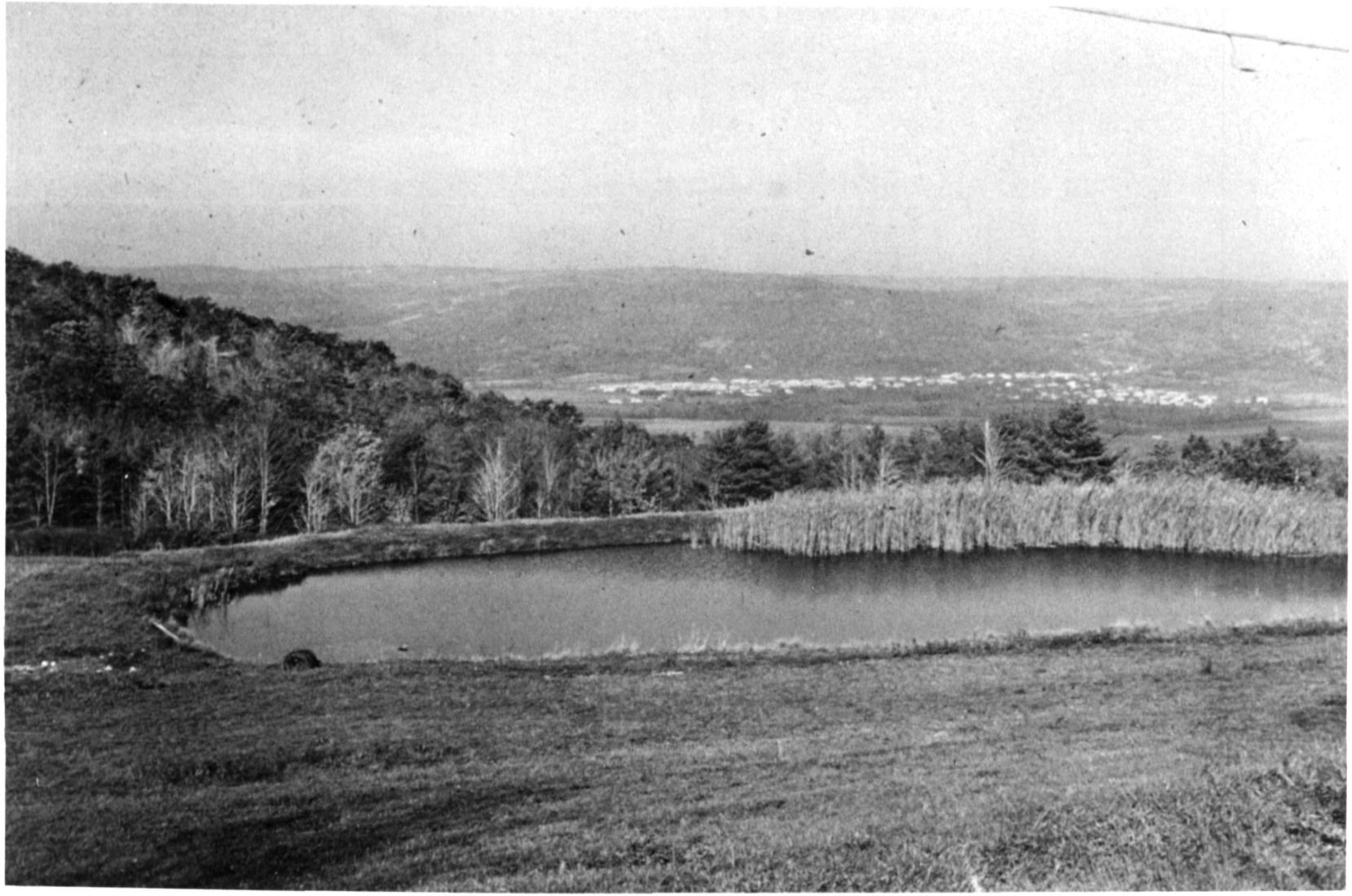


Figure 6. Various examples of land use in a limited area. A frogpond is in the foreground.



Figure 7. A type of commercial development.

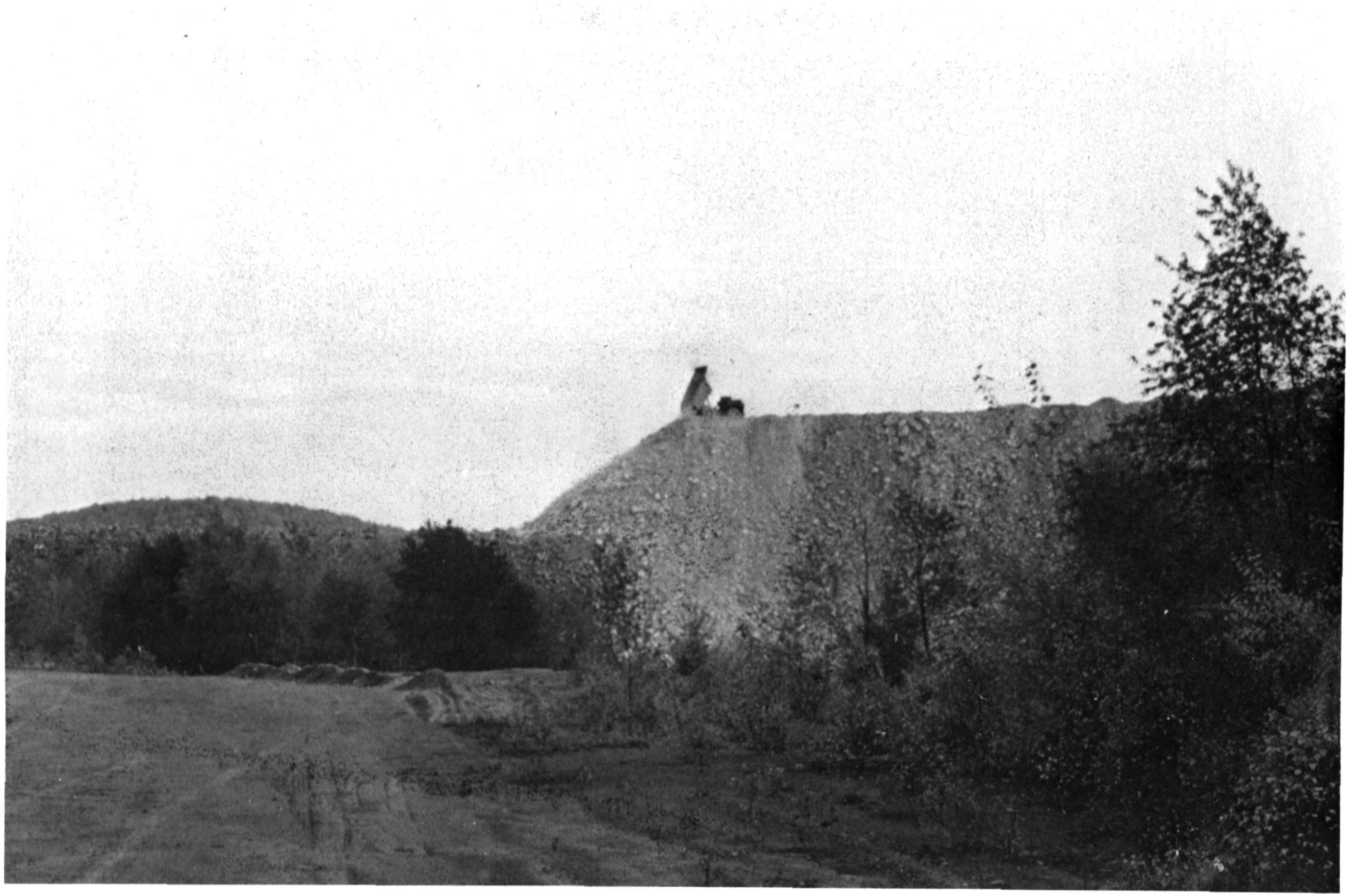


Figure 8. Waste disposal from mining.



Figure 9. One example of solid waste disposal.



Figure 10. Not exactly a landfill, but a necessary kind of land use.

1588



Figure 11. A type of recreational development.



Figure 12. A ski resort.



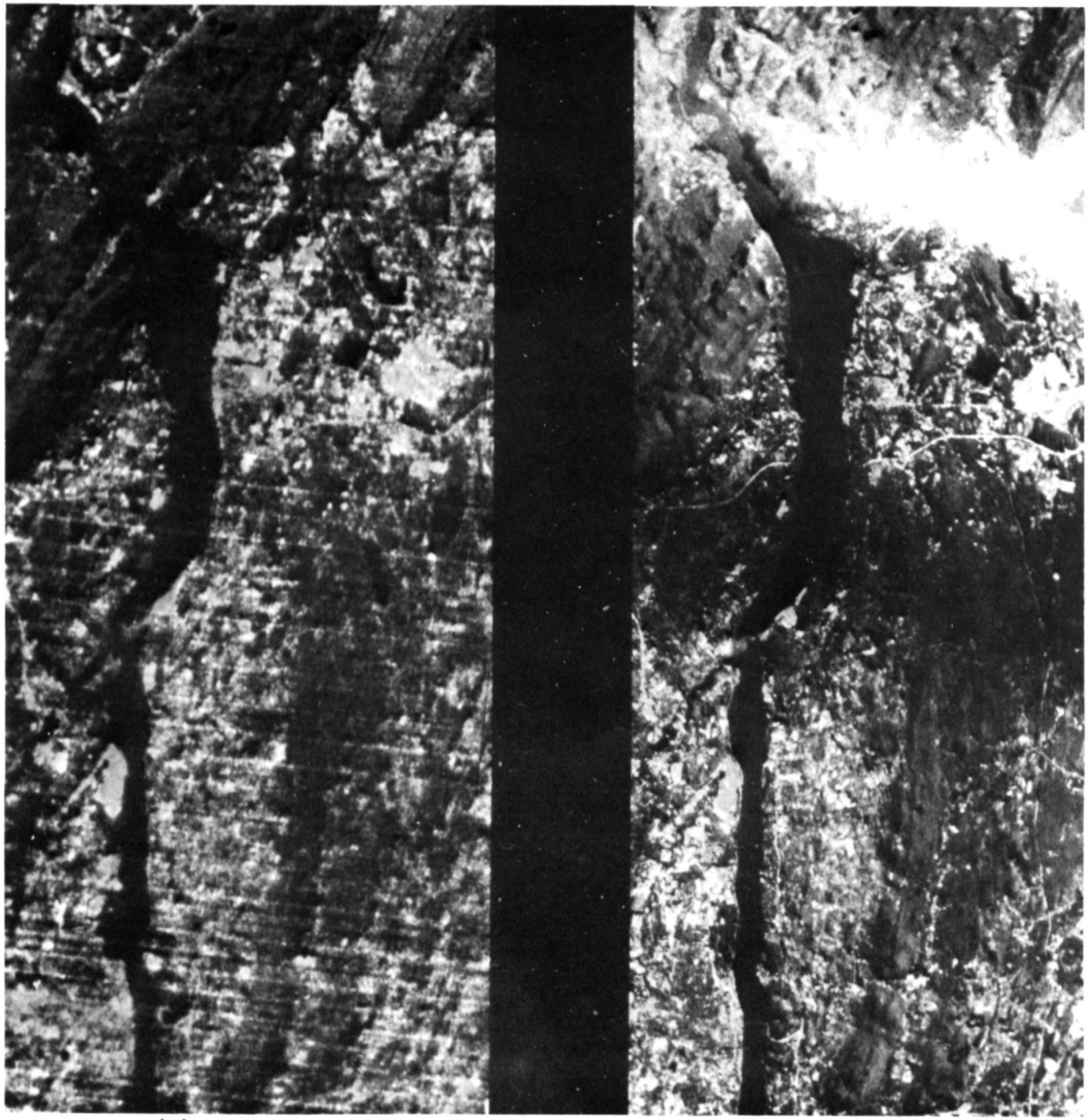
Figure 13. Shoreline development along a lake.



Figure 14. A marina.



Figure 15. One method of locating pollution.



(a) LANDSAT (b) Skylab

Figure 16. A comparison of LANDSAT and Skylab imagery.

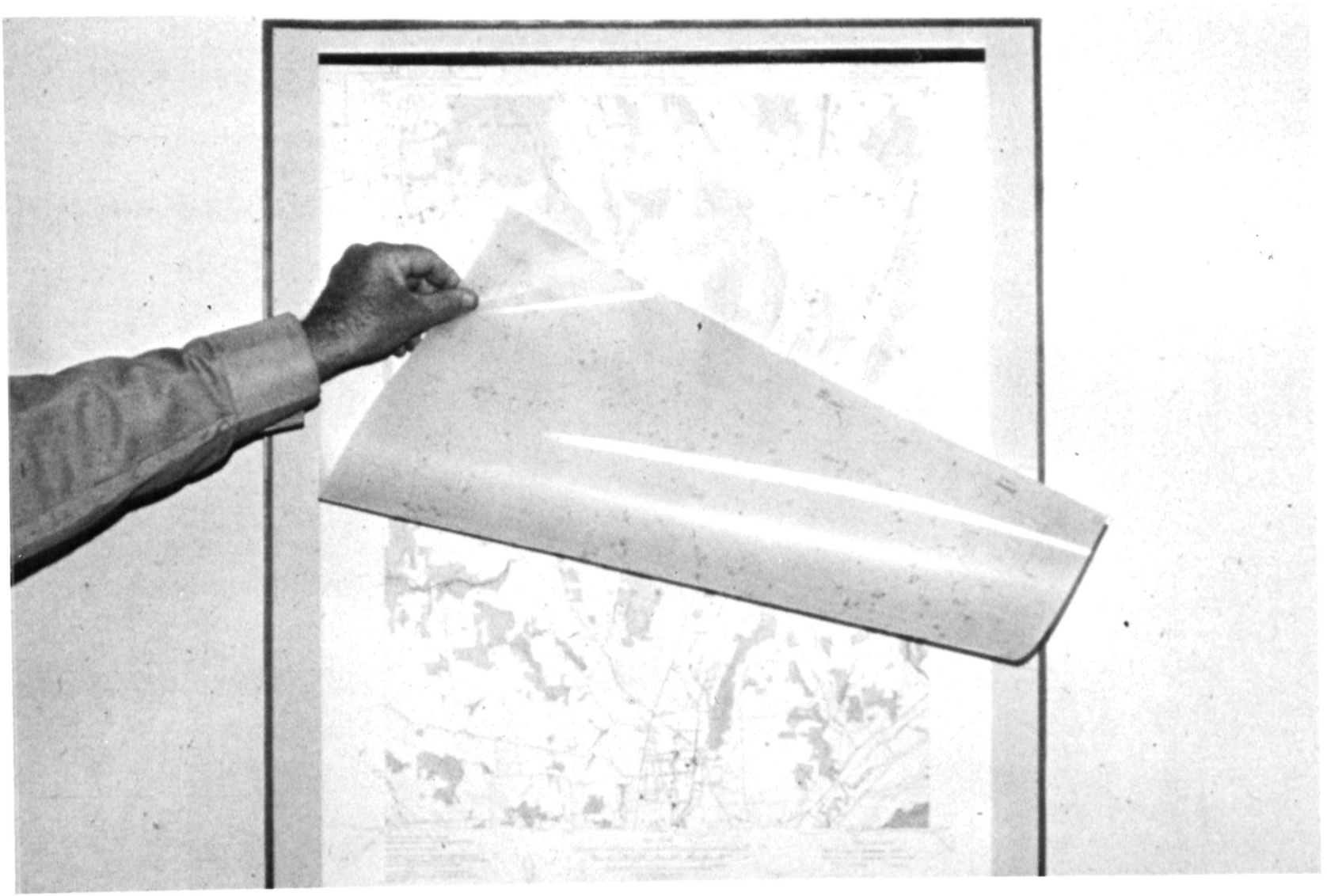


Figure 17. Example of a Mylar map.

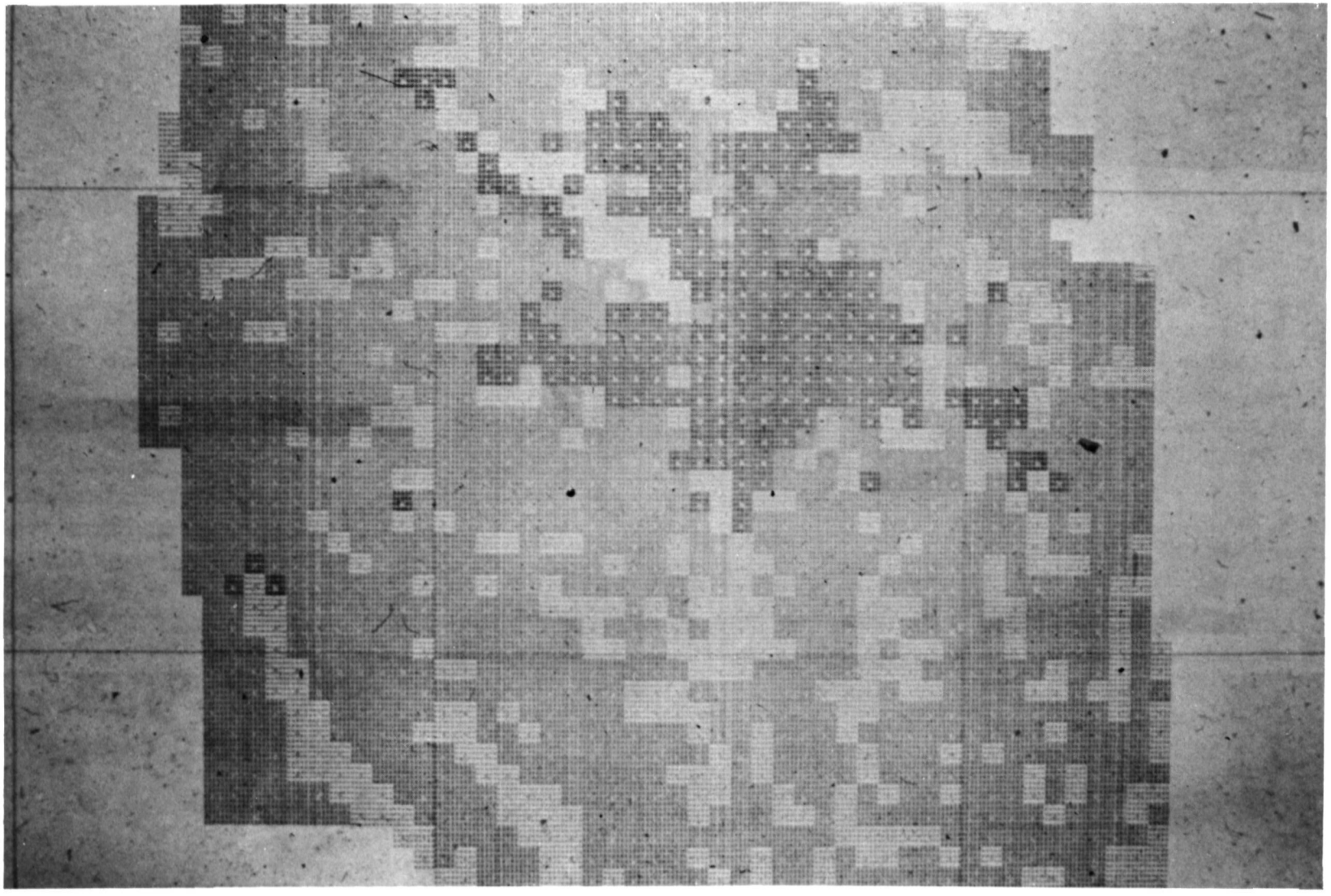


Figure 18. Example of a computer printout.



Figure 19. Digital input system.



Figure 20. Abacus input system.



Figure 21. Plastic input system.

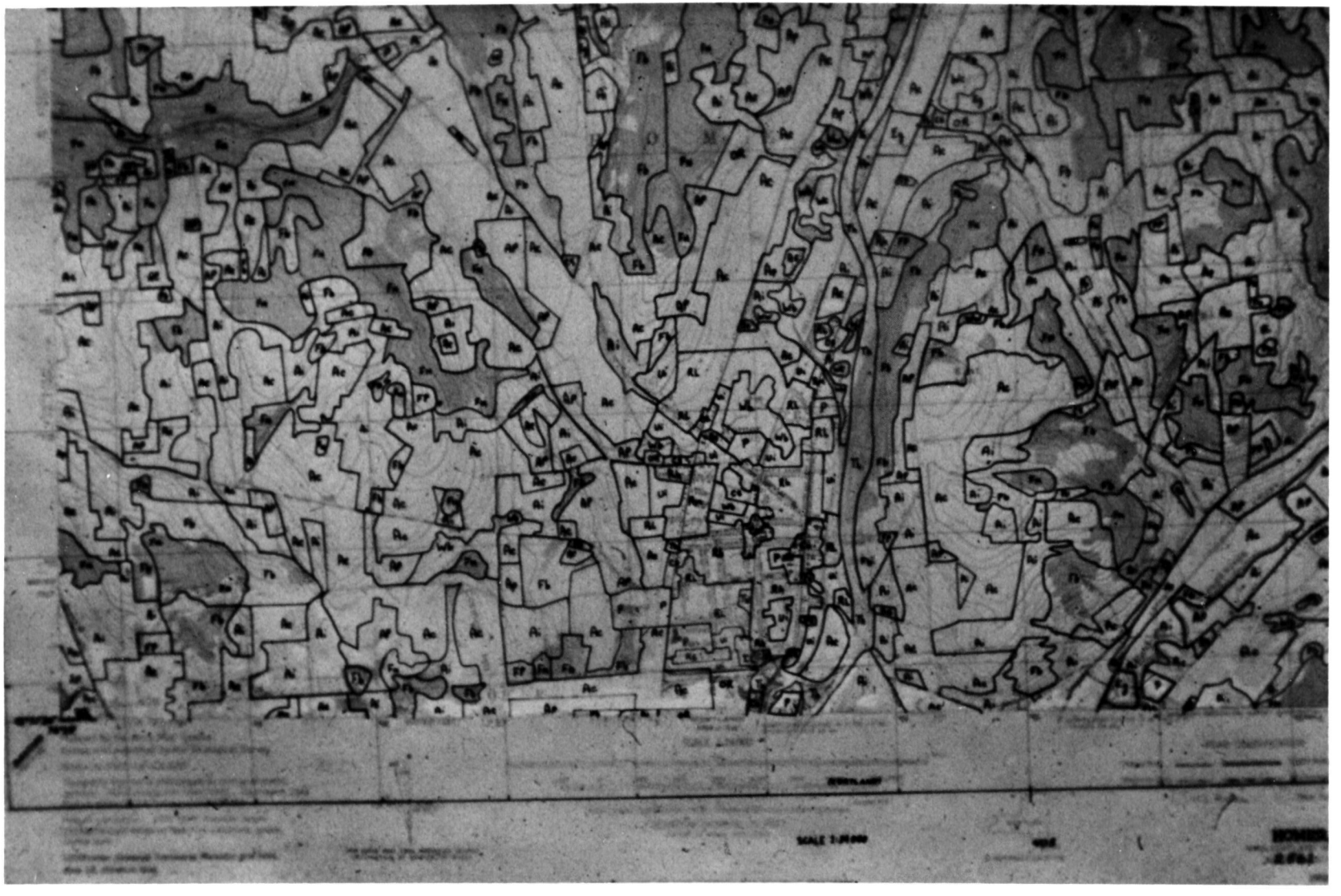


Figure 22. Area map of land use.

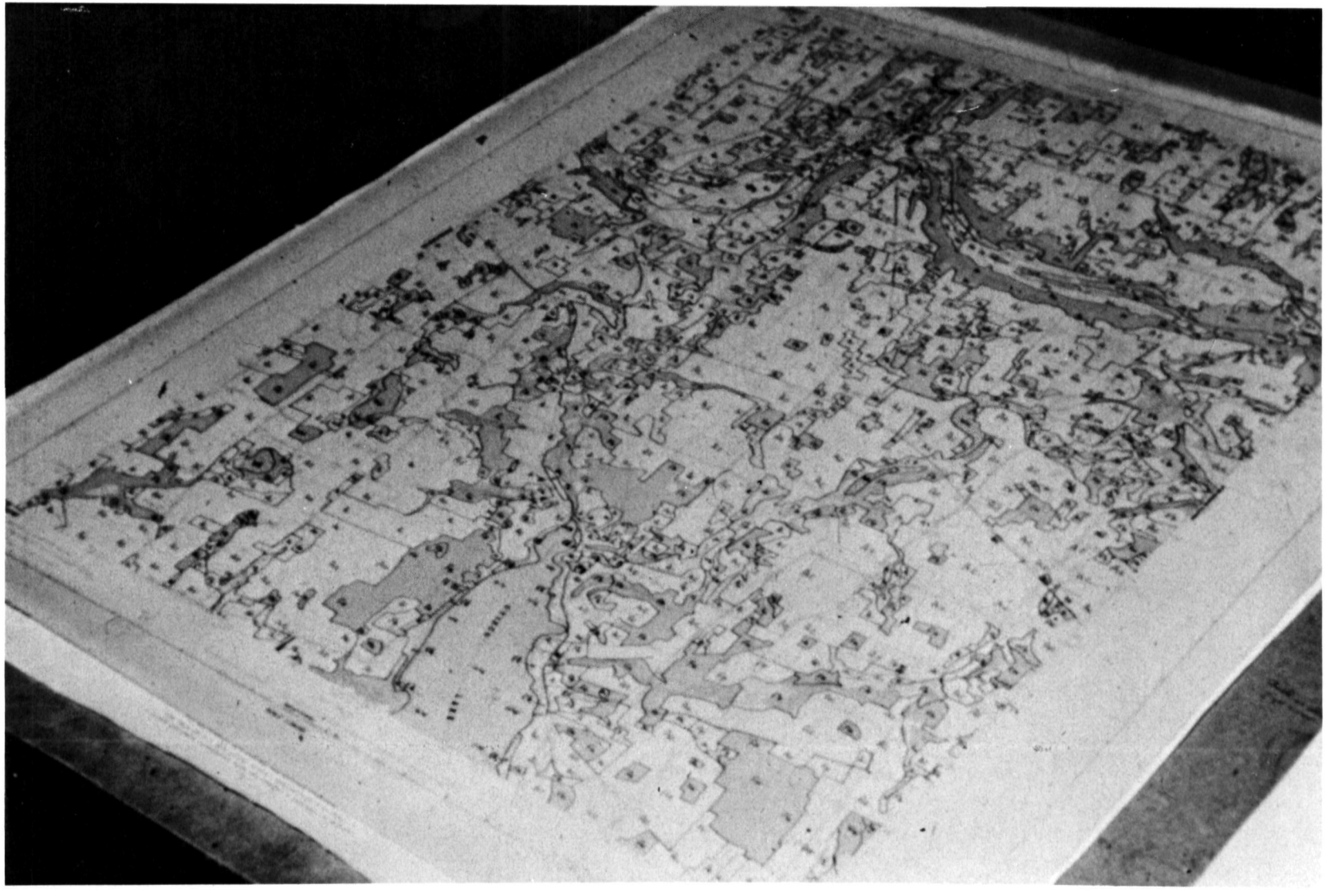


Figure 23. Completed map ready for reproduction.

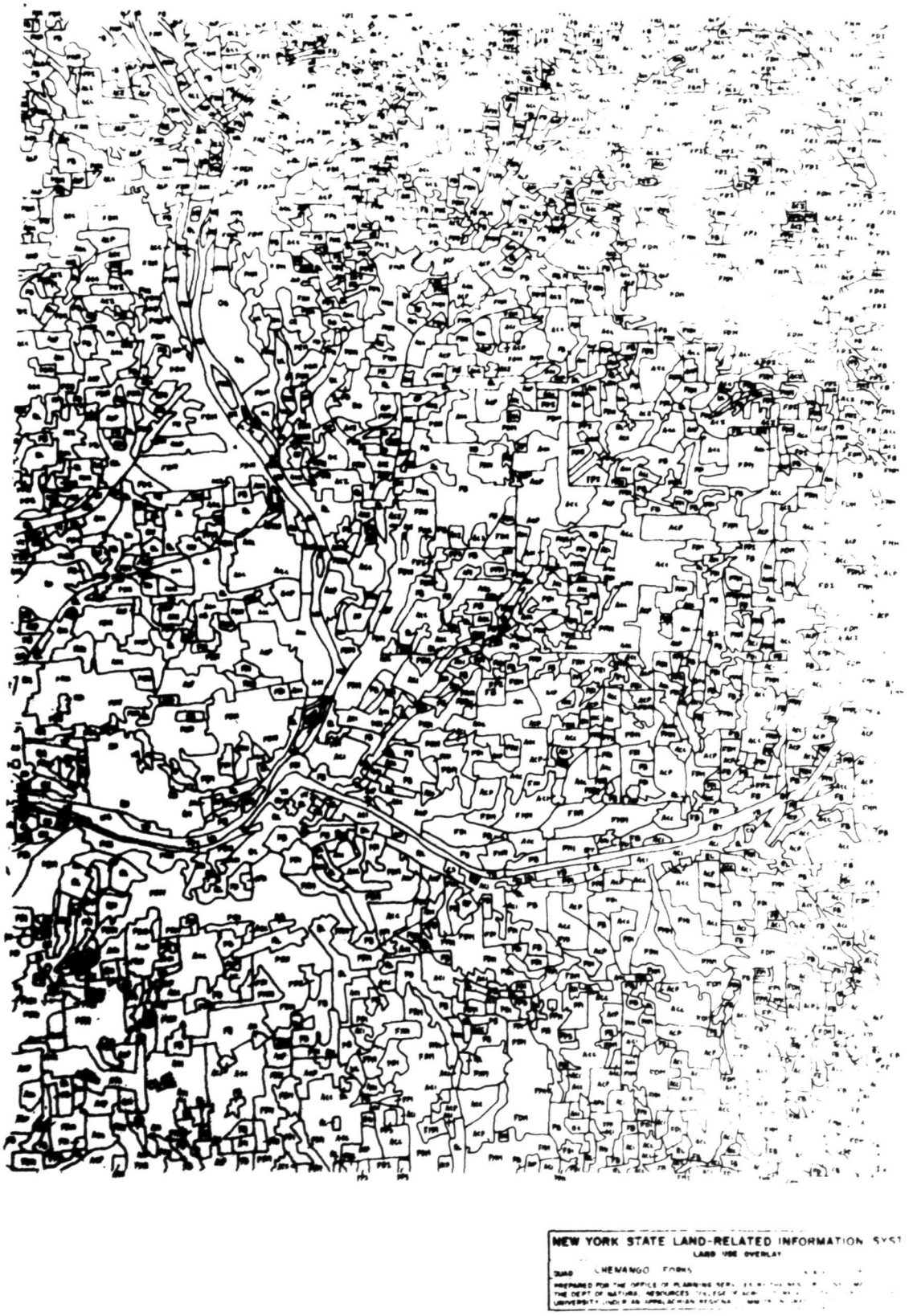


Figure 24. Classification system.

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ALASKAN RESOURCES, CURRENT DEVELOPMENT. TRADITIONAL CULTURAL VALUES, AND THE ROLE OF LANDSAT DATA IN CURRENT AND FUTURE LAND USE MANAGEMENT PLANNING

By Arthur LaPerriere, University of Alaska, Fairbanks, Alaska

ABSTRACT

Past, present, and proposed applications of LANDSAT data for renewable resource assessments in Alaska are described. Five specific projects are briefly discussed. These include a feasibility investigation applying LANDSAT data to caribou habitat mapping in northeast Alaska, analysis of a native corporate region in southwest Alaska, analysis of a game management unit in interior Alaska, and two proposed analyses in northwest Alaska. These analyses principally address range evaluations concerning caribou, moose, and Dall sheep but results have application to other renewable resource themes.

Renewable resources are the traditional basis for land-use and value in Alaska but dramatic land status changes are currently occurring. These changes along with the national demands for non-renewable resources are resulting in rapidly accelerated development. Statewide synoptic resource assessment using LANDSAT data is tenable and, in fact, occurring although not as an organized effort directed to that objective. In spite of this, LANDSAT analyses for the entire State will probably be available by 1980. These results can be utilized in development of a statewide land-use management plan.

INTRODUCTION

Alaska's 586,000 square mile landmass is about 1/5th the size of the contiguous United States. Population is roughly 300,000 and about half of these are concentrated in the greater Anchorage Area. There are only five paved highways and most of Alaska may appropriately be described as wilderness.

The concept of proprietary ownership, particularly land ownership, is foreign to the native peoples of Alaska. Until recently, most Alaskan land was administered as "public domain". Many Native people and others practiced a subsistence lifestyle, hunting, fishing, and gathering edible wild plants. Money to supplement this lifestyle could be earned by trapping, fishing, or temporary employment. Essentially, people lived on the land and used it almost wherever they chose.

Alaska is, however, about to be "owned". Under terms of the Alaska Native Claims Settlement Act, most of the public domain will be divided up: the Federal government may select 83 million acres of "national interest" lands, the native and village corporations are selecting 40 million acres, and the State will select from the remainder. Thus, clearly defined proprietary land ownership will permit rapidly accelerated development and resource utilization. Because of the energy crisis, the focus of this activity is currently directed to petroleum related development. However, the tremendous renewable resources on these lands are the traditional basis for land-use and value. Timber, fisheries, and wildlife are valuable renewable resources traditionally important to Alaskans.

LANDSAT data can play a vital role in a statewide synoptic inventory of many of these resources and provide information permitting formulation of a rational long term land-use management plan. The purpose of this paper is to describe past, present, and projected applications of LANDSAT data to renewable resource assessments in Alaska.

A feasibility study titled "Application of ERTS imagery to the study of caribou movements and caribou habitat" was initiated in 1972. Techniques for mapping vegetation type using LANDSAT data were applied and evaluated. These vegetation types were

were interpreted in terms of caribou range value but similar interpretation for other resource themes such as timber and moose habitat are possible. The most promising technique for detailed analyses of large areas was found to be computerized algorithmic processing of LANDSAT digital data (Lent and LaPerriere 1974).

These results stimulated the interest of agencies involved in forthcoming land selections. As a direct consequence, a LANDSAT based analysis of an entire native corporate region encompassing 58,000 square miles was carried out. Objectives were to map the region to vegetation types which could be thematically interpreted for renewable resource values, such as timber and wildlife habitats. This analysis was principally funded by Calista corporation but subsidized by the U.S. Fish and Wildlife Service.

Currently, analysis of the 53,000 square mile Game Management Unit 20 is in progress. Objectives of this analysis are vegetation mapping and subsequent thematic analyses. The principal thematic analyses for moose habitat will permit formulation of a moose management plan. Other thematic analyses for caribou habitat and Dall sheep winter range will be completed for specific areas of current management concern. This project is jointly funded by NASA and the Alaska Department of Fish and Game.

Habitat mapping of ranges used by the Arctic caribou herd has been proposed and funded by the Sierra Foundation. The Arctic herd is the largest in Alaska, estimated at 250,000 animals. These animals range over approximately 50,000 square miles of northwest Alaska. This project will begin next month and is scheduled for completion within three years.

Analysis of the Seward peninsula for reindeer range has been proposed and will be jointly funded by the U.S. Fish and Wildlife Service and the National Park Service. The analytic area comprises approximately 10,000 square miles and contractual negotiations for the project are in progress.

The scope of this paper does not permit discussion of all LANDSAT applications currently occurring in Alaska. Only the above projects will be briefly discussed. However, several other large scale projects under proposal or in progress should at least be mentioned. These include moose habitat mapping of the Kenai peninsula, analysis of lands being considered as potential sites for the new State capitol, and application of LANDSAT data in development of a coastal zone management plan. These analyses have been or will be based in part on algorithmic processing of LANDSAT digital data.

DISCUSSION

Feasibility Study

Methods - Test sites of homogenous vegetation type were selected using low level aerial reconnaissance. These areas were systematically sampled on the ground using a modified version of a technique for characterization of wilderness vegetation (Ohmann and Ream 1970). Test sites were then identified on LANDSAT data and used interpretively.

A variety of data processing techniques were utilized and evaluated. These included visual interpretation of single band products, visual interpretation of false color composite products, density slicing of single band products, simple algorithmic classification of digital data using multiband density slicing, and data classification using a maximum likelihood algorithm.

Results - Output products included aspect-ratio corrected line printer feature maps and 1:250,000 scale color coded feature maps. More than 7,500 square miles of northeast Alaska were mapped to vegetation type which, in turn, was evaluated as caribou winter range.

Applications - Arctic National Wildlife Range personnel utilized information generated during the investigation. Much of the analytic area consisted of D-2 lands open to selection as proposed additions to the Arctic National Wildlife Range.

Native Corporate Region Analysis

In March of 1974, representatives of a native corporation became aware of the investigational results described above. They requested a comprehensive categorical analysis based on LANDSAT data for their entire corporate region. This area encompasses about 58,000 square miles and results were required by October 1, 1974 for use in first round native land selections. The U.S. Fish and Wildlife Service learned of the proposed analysis and negotiated a contract with the native corporation wherein they would receive analytic results in exchange for financial subsidies.

Methods - Ground truth techniques were similar to those utilized in the feasibility investigation. Native corporate personnel were trained in these data collection techniques and six crews departed to the field in early June.

By late August, they had obtained survey data for approximately 150 test sites. Although these data represented a remarkable field effort, they were insufficient for a comprehensive analysis of the entire region. Therefore, an alternate technique was devised to pursue the analysis beyond the limits of existing ground truth data.

This method might be descriptively termed "interactive spectral cluster analysis". Existing ground truth was utilized insofar as possible for training and feature interpretation. The analysis was then carried to completion using intuitive trial and error training on spectrally consistent cluster classes. After this opportunistic training reached a point of diminishing productivity, i.e., new cluster classes failed to emerge with continued training, CCT data was classified to feature type using a maximum likelihood algorithm.

Feature categorized data were processed through a high speed film recorder interfaced with the processing system. An inter-negative at 1:1,000,000 scale was generated and photographically processed to produce 1:250,000 scale geometrically corrected color coded feature maps.

Results - Thirty-nine feature categorized digital tapes and corresponding 1:250,000 scale color coded feature maps were delivered to the native corporation on September 29, 1974.

Application - Analytic results were utilized in first round native land selections.

Analysis of Game Management Unit 20

Methods - An unsupervised classification technique is being considered. This proposed approach utilizes a cluster analysis applied to 2% of the LANDSAT data to be analyzed. Twenty to thirty cluster classes will be generated and used as a training set basis for classification. Maximum likelihood or table look-up algorithms will be used for data classification. Initial output will consist of "feature categorized" digital tapes and line printer "feature maps". These line printer maps will be used to systematically sample and define each "feature class". It is anticipated that each classification category will correspond to specific vegetation types or subtypes providing a basis for thematic analyses.

A pilot analysis has already been carried out and ground truth data collection is in progress. If ground truth data confirms anticipated results, the remaining data will be analyzed with the same techniques next Fall. If anticipated results are not confirmed by ground truth, the ground truth collected this summer will provide a basis for an interactive supervised analysis.

Anticipated Results - Each category will be evaluated in terms of moose habitat value. These evaluations will permit formulation of a categorical synthesis for moose habitat. From the digital tapes, color coded scale maps of moose habitat will be produced. Similar categorical evaluations for caribou habitat and Dall sheep winter range will be made.

Habitat maps will be produced from digital tapes for specific areas of current management concern.

Anticipated Applications - Results will be initially utilized in game management plan for Unit 20 and to better identify critical habitat areas requiring protection. Successful results, however, will probably be subsequently utilized in a variety of other thematic analyses such as timber and waterfowl habitat.

Arctic Caribou Herd Range Analysis

Method - If techniques delineated above are successful, the same design will be applied to the proposed range analysis in northwest Alaska. This design involves four analytic phases: spectral cluster analysis, algorithmic classification of data to cluster classes, ground truth definition of analytic classes, and categorical syntheses for specific thematic analyses.

This method may prove the most suitable for Alaskan applications for a number of reasons. First, this method does not require interactive mode processing and is considerably less expensive than methods requiring use of an interactive system. These cumulative cost benefit savings are substantial in Alaskan applications requiring large volume processing.

Second, spectral categories generated in the analysis have a higher probability of correspondence to natural geobotanical assocations rather than artifacts of human disturbance. Because the analytic areas are principally undeveloped and sparsely populated, natural vegetative cover exists and atmospheric variations are much less complex than in more populated areas.

Third, this method utilized a clearly defined goal directed ground truth effort. Sampling is carried out in specific areas to define each analytic class and continues only until class variability begins to diminish asymptotically. Therefore, the field effort is reduced to the necessary minimum and, in Alaska, field operations are usually the most expensive cost item.

Fourth, results should be useful to a variety of thematic analysts. While the stated objective of this project is a caribou habitat analysis, utility of results will not be confined exclusively to this application. A number of subsequent thematic analyses may be possible.

Anticipated Results - Caribou habitat maps covering about 50,000 square miles of northwest Alaska will be produced within the next two years.

Projected Applications - The caribou habitat analysis and subsequent thematic analyses would logically be used in preparation of the environmental impact statement for proposed development of Petroleum Reserve #4. Other applications might include use in formulation of game management and land-use plans for areas such as the proposed Kobuk National Monument and Selawik National Wildlife Refuge, as well as on native corporation lands.

Seward Peninsula Analysis

Methods - Techniques similar to those described above will be utilized.

Anticipated Results - Caribou/reindeer range maps of the Seward Peninsula will be produced within the next three years.

Projected Applications - Results will be utilized by the U.S. Fish and Wildlife Service, the National Park Service, and the regional native corporation. A cooperative management plan for reindeer introductions and expansion of existing herds will be developed.

CONCLUSIONS

Alaska currently offers unique opportunities for remote sensing research and applications particulary in the fields of ecology and land-use planning. Because large relatively undisturbed areas exist in seral climax, synoptic investigations of geobotanical climatic associations are possible with LANDSAT data.

Algorithmic machine processing of LANDSAT data provides a vehicle for statewide renewable resource assessment at a critical period in Alaska's history when rational land-use planning remains a tenable alternative. Although petroleum and mineral development is occurring at a remarkably rapid pace, most of Alaska will remain undeveloped for many years. The land status changes authorized under the Native Land Claims Act will probably be argued in our judicial system for years and perhaps even decades.

During this period, statewide renewable resource assessments based on LANDSAT data are possible. This is, in fact, occurring but not as an organized effort addressing that objective. In spite of this, almost 50% of Alaskan lands will be analyzed with LANDSAT data by mid-1977. At this rate, similar analytic results may be available for the entire State by 1980. These results could be utilized in formulation and implementation of a long term land-use management plan before uncontrolled development destroys such planning options.

Whether this will or will not actually occur is difficult to predict. It seems almost a certainty that the analytic results will be available but development of a cooperative land-use management plan involving Federal agencies, the State government, and the Native corporations may be a task of great difficulty. The logical focal point for coordination of a state-wide land-use planning effort lies within the State government and the Hammond Administration has already taken steps in this direction. Therefore, if the Alaskan legislature is responsive to Governor Hammond's leadership, we can be optimistic that Alaskan resources will be considered "in toto" with long range management addressing wise use of renewable resources and orderly planned development of nonrenewable resources.

ACKNOWLEDGEMENTS

The list of persons participating in the projects described is quite long. Drs. Peter Lent and David Klein of the Alaska Cooperative Wildlife Research Unit are principal investigators of four of these projects. Their direction and leadership made these projects possible.

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REFERENCES

Lent, P. C. and A. J. LaPerriere. 1974. Application of ERTS imagery to the study of caribou movements and winter habitat. Final report to NASA on contract NAS5-21833.

Ohmann, L. F. and R.R. Ream. 1971. Wilderness ecology: A method of sampling and summarizing data for plant community classification. U.S.D.A. Forest Service Research Paper NC-49. North Central Forest Experiment Station, St. Paul, Minn. 14pp.

THE NATIONAL LAND USE DATA PROGRAM OF THE U.S. GEOLOGICAL SURVEY

L-7

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ABSTRACT

The Land Use Data and Analysis (LUDA) Program will provide a systematic and comprehensive collection and analysis of land use and land cover data on a nationwide basis. The initial nationwide collection of these data will be completed within a 5-year period. Individual land use/cover maps and their associated data will be released as they become available following compilation. Periodic revision of the data is planned.

Maps will be compiled at about 1:125,000 scale showing present land use/cover at Level II of a land use/cover classification system developed by the U.S. Geological Survey in conjunction with other Federal and State agencies and other users. For each of the land use/cover maps produced at 1:125,000 scale, overlays will also be compiled showing Federal land ownership, river basins and subbasins, counties, and census county subdivisions.

The program will use the advanced technology at the Special Mapping Center of the U.S. Geological Survey, high altitude NASA photographs, aerial photographs acquired for the USGS Topographic Division's mapping program and LANDSAT data in complementary ways.

INTRODUCTION

In the United States there has been no systematic and comprehensive compilation of land use/land cover maps and data similar to land use mapping carried out in Canada, Japan, the United Kingdom, and most other European countries. However, much mapping of land use has occurred in the metropolitan areas of the Nation. Much of this compilation of land use maps and data in urban America has been carried out with assistance from the U.S. Department of Housing and Urban Development.

Some States such as Connecticut,[1] New York,[2] and Minnesota,[3] have, for some time, had maps of land use at scales ranging from 1:24,000 to 1:500,000, but in most cases these States have not been able to update their land use maps regularly. Therefore, they have decreasing utility. Some Federal agencies, such as the Forest Service, Soil Conservation Service, and Bureau of Land Management, collect some land use information, but it is generally collected for a specific need and it is generally difficult to adapt to other uses. In 1958, and again in 1967, a National Inventory of Soil and Water Conservation Needs was carried out by the U.S. Soil Conservation Service.[4] The inventories have provided much useful information about land uses by counties, but since the inventory was based on a 2 percent sampling of the total area of the United States it is deficient with respect to specific geographic distributions of various land uses.

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Some of the major problems with these existing data sources are the lack of consistency, the age of the data, spotty coverage, and the use of incompatible classification systems. The data have been collected to meet specific limited needs using definitions of use classes which are appropriate only for that need. They have often been collected on a one-time basis so the data are of marginal utility for other applications at a later time. Furthermore, it is nearly impossible to aggregate available data because of the differing classification system used.

LAND USE - LAND COVER CLASSIFICATION

The Land Use Data and Analysis (LUDA) Program of the U.S. Geological Survey has been designed and funded to provide a systematic and comprehensive collection and analysis of land use and land cover data on a nationwide basis. The initial collection of these data is to be completed within a 5-year period. Individual land use/cover maps and their associated data will be released as they become available following compilation. Periodic revision of the data is planned.

A major necessary first step in establishing the Land Use Data and Analysis Program was to develop and test a land use classification system appropriate for use throughout the United States at the more generalized first and second levels. At the same time it was necessary to recognize the need for flexibility in meeting regional and local needs for land use/land cover maps and data.

A Land Use Classification System for Use with Remote Sensor Data published by the U.S. Geological Survey as Circular 671, 1972,[5] and the revised circular now nearly ready for publication under the title, A Land Use and Land Cover Classification System for Use with Remote Sensor Data have been prepared to meet that need. In the preparation of these reports, the authors have had the benefit of extensive and extended discussions with informed persons from Federal, State, and local governmental agencies as well as from universities, professional societies, and elsewhere.

In developing the Geological Survey system of land use and land cover classification, several needs were kept clearly in mind. Some of these were:

1. Recognition of frequently used existing categories of land use and land cover in order to make it possible to have an adequate understanding of the general framework of the classification system. It was considered absolutely essential in order to attain a reasonable, though not necessarily ideal, level of standardization for land use mapping and data collection. Sophisticated but unfamiliar terminology was carefully avoided although a more refined approach to the classification of land use and land cover might be more acceptable to those seeking to institute a classification system which gives more attention to logic than to practicality.

2. Provision for adequate flexibility in using the proposed approach to standardization at the more generalized levels of classification was absolutely necessary. From the beginning it was recognized that what was one man's prime concern was another man's miscellany. Later I will illustrate how various users of the Geological Survey classification system have been able to achieve the flexibility needed in their respective programs.

3. Application of the available and rapidly expanding array of remote sensor technology was considered a prime consideration in developing a framework of land use and land cover classification. Funds for data collection are always scarce. Too often we fail to ask the important question: What is the minimum amount of data that is needed for planning, management, and regulatory purposes? We also generally fail to be realistic about the funds and time needed to obtain data for a specific need. Data not exactly applicable to a specific use may be available at a fraction of the cost of generating data sets for each highly specific use. Remote sensor data will definitely not supply all user needs for land use and land cover data, but remote sensing offers an efficient and timely approach to obtain much data to which data from other sources can be conveniently added.

4. Recognition of the need for objectivity is absolutely essential in providing benchmark or baseline data pertaining to land use and land cover. Without a means of quantifying the use and character of land resources on a consistent, repetitive basis, an important dimension of land use planning is sorely neglected. Unless careful attention is given to the selection and definition of land use and land cover categories, objectively assembled data will not be available for the measurement of changes in land use and land cover over time or from place to place.

5. Assignment of single use or cover designations to a given area of land seems necessary and preferable to the recognition of multiple uses which might be applicable to such an area. The multiplicity of uses can best be handled by employing the overlay method rather than by using combinations of use and cover categories. For example, when an area of forest land is used for the production of timber, grazing of livestock, recreation, and wildlife habitat, an additional map or maps is really needed to depict such a multiple use situation properly. To establish a category that would identify such a combination of uses in the basic data set creates specific problems in recovery of basic land use and land cover data for other purposes.

The words "land cover" have been added to the title of the USGS classification system being published in the revision of Circular 671 in order to indicate more clearly the intermixing of land use and land cover terminology in the classification system. To some this intermixture is undesirable. However, a careful evaluation of alternatives leads the authors to the conclusion that unfamiliar or infrequently used terms would need to be introduced if strict adherence to either land use or land cover terminology was observed

LAND USE DATA AND ANALYSIS PROGRAM

Turning now to the Land Use Data and Analysis (LUDA) Program of the U.S. Geological Survey, I would like to review briefly the main components of the program and to cite several examples of how land use/land cover data being compiled are being interfaced with third level categorization to meet specific needs of cooperating State, Federal and metropolitan agencies.

Maps are being compiled at a scale of approximately 1:125,000. For each of the land use/cover maps produced, overlays will also be compiled showing Federal land ownership, hydrologic units, counties, and census county subdivisions. State land ownership will be shown when information is made available to the U.S. Geological Survey by the appropriate State agency or agencies on a Statewide basis.

Land use and land cover data will be keyed to the combined black and blue color separation plates of the standard USGS 1:250,000 topographic sheets. The minimum mapping unit for urban and built-up uses, water areas, confined feeding operations, other agricultural land, and strip mines, quarries, and gravel pits is 10 acres. All other categories are being delineated with a minimum unit of 40 acres. Federal land holdings will be shown for tracts of 40 acres or larger.

Selected experimental demonstration land use and cover maps at scales from 1:24,000 to 1:100,000 are also being prepared in order to show how land use and cover mapping carried out at a regional scale can be related to more detailed land use and cover mapping at larger scales.

Computerized graphic displays and statistical data on current land use and cover will become available through this program for use in conjunction with other data. Statistical data will be compiled by counties, by areas of Federal ownership, by hydrologic units, and by statistical units such as census tracts or other census county subdivisions.

Land use and cover data will be digitized in polygon format (each individual land use/cover area comprising a polygon). Conversion of land use polygons to land use grid cells of varying sizes can be made when desired.

Because of the dynamics of land use, the emphasis in the preparation and distribution of all products is on supplying the information to the users in the shortest possible time. There are three stages of release of land use and land cover information.

A) Maps will be available for advanced sale on ozalid paper, ozalifoil, semi-stable ozalid, cronar, and cronaflex materials. The standard land use/cover maps and accompanying overlays showing counties, hydrologic units, Federal land ownership, and census county subdivisions will be available at 1:250,000 on the materials just mentioned. However, these products will also be available upon request within a reasonable range of the compilation scale of approximately 1:125,000. For example, under the cooperative agreement with the State of Florida, land use/cover maps are being supplied at a scale of 1:126,720 in order to match the scale of county highway maps in common use in that State.

B) Computer-generated maps and statistical data are to be made available upon request about 6 months after land use/cover maps and accompanying overlays have been made available as indicated above. Magnetic tapes will be available for sale. Documented software needed for the use of computer-generated data will also be available. Of course, computer-generated maps can be supplied at any scale compatible with the original compilation scale of approximately 1:125,000. (It is, of course, inappropriate to use land use/cover data compiled at that scale at such scales as 1:24,000 or 1:50,000 on the one hand or at such scales as 1:1,000,000 on the other hand.)

C) Lithographed published maps in color.

The LUDA Program will use the advanced technology at the Special Mapping Center of the U.S. Geological Survey, high altitude NASA photographs, aerial photographs acquired for the USGS Topographic Division's mapping program, and other supplemental data necessary for the effective compilation of land use/land cover maps. LANDSAT data will be used in complementary ways.

As stated earlier the approach to land use and land cover mapping by the U.S. Geological Survey permits an aggregation of Level II categories into Level I categories. Even more important is the capability to add Level III categories desired by users. Such categories would represent further subdivision of Level II categories already compiled.

For example, under a cooperative agreement with the State of Florida, land use and cover data are being compiled at Level II. At the request of the Florida State Department of Planning, an overlay of selected Level III-type categories is being prepared. The cost of this overlay is being borne by the State. Some of the Level III categories being overlaid and fitted to the Level II categorization are:

1. citrus groves separated from other groves, nurseries, etc.
2. mangrove swamps and cypress bogs separated out of the Level II category "Forested Wetland"
3. mudflats separated out of non-forested wetland

One of the current cooperative agreements involves the Level II land use/land cover mapping for the area of the new 1:100,000 topographic base map of the Atlanta Region for the Georgia State Geologist. In conjunction with this mapping, certain additional Level III categories are being supplied at the request of the Atlanta Regional Commission for the eight-county area of its jurisdiction. These include the separation of single-family and multi-family residential units, the breakout of major institutional areas from the Commercial and Services category, the delineation of urban parks, and a further breakdown of areas classified as Mixed Urban or Built-up at Level II. In order to permit digital and statistical extraction and comparison of data for areas of local and regional interest, additional overlays depicting municipality boundaries and local watersheds are being compiled. These additional products and categorizations are examples of accommodations which make the techniques of a national program useful in a local context.

Separation of additional Level III-type categories such as saline and freshwater marsh will generally require more extensive use of data acquired by other means than remote sensing. This flexibility is obviously needed to accommodate varying needs for land use data from place to place and agency to agency. Such flexibility even permits restructuring the emphasis in the generalization process so that a Level III category from a nationwide perspective can be elevated to Level I in a particular State or region. Compatibility with the U.S. Geological Survey mapping will be maintained if the categories which are added can be combined into Level II categories.

There has been considerable experimentation in the Geography Program on the potential of LANDSAT data for providing Level II land use/land cover information useable for land use mapping. This has included both visual and automated interpretation, and certain aspects of both procedures are being described in other

presentations from the USGS Geography Program at the Symposium by Alexander and Wray. General results of this interpretation of LANDSAT data indicate that most Level I categories can be obtained either visually or through automated classification of CCT spectral data. Although certain Level II categories usually can be obtained either visually or automatically, the entire range of Level II categories has not been obtained consistent with the definitions as specified in USGS Circular 671. More importantly, repetition of categories from scene to scene and region to region has not yet been achieved. The results of our research on the potential of LANDSAT data for land use and land cover mapping generally parallel the results obtained by other researchers concerned with similar problems. The several State land use maps that have been produced through conventional interpretation of LANDSAT data, such as the maps for Kansas,[6] Nebraska,[7] and Tennessee,[8] are indicative of the problems of level of classification and consistency of definition. Similar problems have been encountered by those attempting to assign land use and land cover categories to LANDSAT spectral data.[9,10,11]

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REFERENCES

1. Connecticut, Dept. of Finance and Control, Office of State Planning, 1970, 1970 Land use study for Connecticut, unpub. report.

2. New York, Office of Planning Services, 1972, Land use and natural resources inventory of New York State, LUNR classification manual: Albany, June 1972, 23 p.

3. Minnesota, Univ. of Minnesota Land Management Information System Study, 1971, State of Minnesota land use, 1969: Minnesota Land Management Information System Study map prepared under contract with the Minnesota State Planning Agency, scale: 1:500,000.

4. U.S. Dept. of Agriculture, Basic statistics: national inventory of soil and water conservation needs, 1967: Statistical Bulletin No. 461, Washington, D.C., 211 p.

5. Anderson, James R., Hardy, Ernest E. and Roach, John T., 1972, A land-use classification system for use with remote-sensor data, U.S. Geol. Surv. Circ. 671, 16 p.

6. Williams, Donald L. and Barker, Bonnie L., 1974, Map of Kansas land-use patterns, summer, 1973, Univ. of Kansas Space Technology Laboratories and Kansas Dept. of Economic Devel., Lawrence, Kansas, scale: 1:100,000.

7. Univ. of Nebraska Remote Sensing Center, 1974, Map of general land use in Nebraska, summer, 1973, scale: 1:100,000.

8. Wilson, John M., 1973, Map of Tennessee land use, Tennessee State Planning Office, scale: 1:633,600.

9. Joyce, Armond T. and Derbonne, J. D., 1975, A computer implemented land use classification technique applied with ERTS digital data acquired over southern Missouri: NASA Earth Resources Laboratory Report No. 143, 43 p.

10. Erb, R. Bryan, 1974, The ERTS investigative (ER-600): A compendium of Analysis results of the utility of ERTS-1 data for land resources management, NASA Technical Memorandum X-58156, pp. 6/1 - 6/15.

11. Haralick, R. M. and Barr, B. G., 1974, An investigation of the feasibility to automatically develop a land use map of Kansas: Univ. of Kansas Center for Research - Final report, Agency contract No. 73, 40 p.

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CASES IN THE RELATION OF RESEARCH ON REMOTE SENSING TO DECISIONMAKERS IN A STATE AGENCY

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ABSTRACT

Research on the application of remote sensing can be used effectively in solving problems of water quality and land use if researchers and the state agency personnel having responsibilities in this area work together to assure that research projects and agency needs are closely aligned and remain so. However, developing goals and projects that fit the requirements of research units as well as the state agencies, profit by the use of several management tools. This paper describes the characteristics of several processes that transfer research results to the government agencies. Then the management of three projects and the Data Center are delineated to illustrate the application of these tools in the effort to guarantee the applicability of university research to agency needs.

I. INTRODUCTION

Research on the application of remote sensing to the problems of water quality and of land use can be valuable to state and regional governmental agencies that have responsibilities for planning, monitoring, and enforcement in these areas. But in order that the research results mesh with agency needs, conscious efforts must be made to assure that research and needs are closely related and remain parallel or converge.

In the course of research on several remote sensing projects at the University of Wisconsin, observations were made of the use of various management tools in order to assess their effects on the anticipated relevance of the remote sensing research to the needs of these government agencies. Among these tools are different organizational structures and ways of functioning, which are applied to the design and management of projects and to the communication of research results. The observed events on which this paper is based were not controlled experiments but were planned attempts to assess the methods while the remote sensing projects--centered on the scientific understanding of the physical events involved--continued. Members of the research teams chose to try to solve by the use of these different management tools the communication and relationship problems that developed in the natural course of the research. Solving these problems makes available to agency use material and technology previously obscured from their view.

The results of remote sensing projects can be used by a governmental agency in any of several ways.

1. The agency secures data or information it needs:
   e.g., the area within a particular isotherm in a power plant thermal plume.

2. The agency uses technology transferred to it from the research body:
   e.g., a technique for monitoring eutrophic levels of a lake.

3. The agency gains a theoretical understanding of a problem it faces:
   e.g., why thermal plumes behave as they do under certain wind and wave conditions.

This paper treats only the first two of these uses: (1) data and information flow, and (2) technology transfer.

After discussions of the characteristics of these processes, the paper illustrates in the management of three projects and a remote sensing data center the use of some tools for influencing these processes.

II. CHARACTERISTICS OF THE PROCESSES OF DATA AND INFORMATION FLOW AND TECHNOLOGY TRANSFER

A. Data and Information Flow

The elements of the flow of data and information in a remote sensing operation may be viewed as a process of communication across the interfaces between different roles necessary to the process (see Figure 1). An interface in this process is a point at which the output of one part or role of the process becomes the input to another part. A group may perform one role, an individual may, or several roles may be performed by one individual. This description is an adaptation of the standard military diagram for the basic information cycle.[1]

In a simple case, the flow of communication through this process is supposed to begin with the person in Role 1--Decision Making--articulating a problem to someone in Role 2--Analysis and Interpretation: e.g., How can we more often update land cover information for land use planning? The problem is analyzed in Role 2, resulting in tasks being assigned to persons in Role 3--Data Processing: e.g., Can land cover maps showing urban, forest, agricultural and wetlands areas be produced and updated every six months? This step may involve the communication of tasks in several directions for different areas of investigation which may be alternatives or different phases of the analysis of the problem. Data Processing Role, upon receipt of the tasks, determines how data can be acquired to fulfill the tasks and plans missions for this acquisition: e.g., Get LANDSAT data for April and September 1975. In the Data Acquisition Role, when raw data are secured they are communicated to the Data Processing Role: e.g., LANDSAT tapes April and September 1975. The information is extracted from the data in the Data Processing Role to produce maps that become the input upon which the Analysis and Interpretation Role now studies the problem with which the process was started. Comparison of these maps with other sources of information is made and, on the basis of this, recommendations go to Decision Making: e.g., Compared to maps produced by ground parties, accuracy and cost of remotely sensed maps have these advantages and limitations. On the basis of these recommendations, the decisionmakers now have the possibility of a decision about the problem that was raised in the first place.

The above description is referred to as the simplest case because it is assumed that the roles (1), (2), (3), and (4) are clearly defined and performed by separate persons and that communication at the (1)-(2), (2)-(3), (3)-(4) interfaces is uninhibited. In none of the projects described in this paper were these assumptions true. Lack of clarity in the roles of the decisionmakers and of the analysts and interpreters led to an emphasis on clarifying these roles. The interfaces at which communication was needed in the projects studied here, but at which observation indicated communication was not clear, were those from (1) to (2), (2) to (3) and (2) to (1) (Figure 1).

Some of the complications involving role (1), role (2), and the interface (1)-(2) and (2)-(1) were the result of uncertainty about the boundary between roles. In most cases, decisionmakers were in a state agency, but some of the analysts and interpreters were in the same state agency. Other analysts and interpreters were researchers in the university. The boundary between university personnel and state agency personnel within the Analysis and Interpretation role at times produced groups with two distinct points of view, each doing analysis and interpretation. In these cases the simple diagram should be augmented, as in Figure 2. The interface between (2A) and (2B) is subject to the possibilities of misunderstanding between the research world and the practitioner world discussed in Section II.B.

The interface between (2) Analysis and Interpretation and (3) Data Processing is difficult because the experience of researchers within the university has led them not to be clearly aware of distinctions between roles. In most research projects, analysis of the problem, formulation of tasks, data processing, production of information, and interpretation of information are all combined in the work of one person or one coherent group. Communicating with others in an extended process or confining himself to one distinct role while someone performs another on which he is dependent are unfamiliar skills for many university researchers. This unfamiliarity with these role distinctions may mean that research does

not produce recommendations that would be of use to a decision-making person, but would be useful for making conclusions about hypotheses that were to be tested. A university researcher may believe that he has completed the whole project when, in fact, the information flow sequence has not been carried to the point where a useful product has been produced. There is no reason why one person cannot occupy several roles in this process, but experience indicates that it is important for each individual or agency to recognize as clearly as possible what the different roles are and how they relate to the roles on either side in the flow sequence.

To help the data and information flow process to proceed efficiently, it became an objective of management of the projects involved to improve communications across the interfaces between roles in the process and to clarify the distinct roles. Understanding of a person's role and of other roles in the process seemed to be one of the best tools for improving this communication. Another tool was clarifying the boundaries between agencies, and relating them to distinctions in role. Dialogue, or extended two-way communication with persons on the other side of an interface, was another tool useful for improving communication. Finally, inclusion of persons in all the various roles of the data and information flow in the early planning of projects was an essential tool.

B. Technology Transfer

When an objective of research is to provide a means by which a governmental agency may solve a problem confronting it without continued dependence on the research organization, the transfer of technology becomes crucial. While many of the staff members of state agencies are scholars at work in the application of scholarship, their positions in governmental agencies make it most likely that they operate as practitioners of science rather than as researchers of science. In his article "Relations between Researchers and Practitioners," James P. McNaul [2] lists some areas of difference between researchers and practitioners. The following are adapted from his list with illustrations from Wisconsin projects.

1. The value system of technology, or of the practitioner, is the use of knowledge: "We need a practical way to clean up the lake water." For science, or the researcher, the value system is the increase of knowledge: "We need to understand lake eutrophication."

2. The primary communication pattern for practitioners is through technical agencies or companies: "We'll talk to the Corps of Engineers or consultants from water treatment companies." The primary communication pattern for researchers is through scientific journals: "We'll have to do a literature (journal articles, not brochures from practical companies) search."

3. The time frame required of practitioners is generally short: "We need a plan to show some progress in cleaning up lakes before the end of this year." That for researchers is longer: "This will take about the three years that a graduate student usually requires to complete a research project in collaboration with a professor."

4. Practitioners must be concerned about uniqueness in their products or policies: "Clear Lake is becoming choked with weeds and swimmers and boaters want to have it cleared up." Research scientists are most interested, on the other hand, in the discovery of patterns that constitute theoretical principles that can be generalized: "We need to understand whether the weed growth is a perfectly normal phase in the lake ontogeny."

5. Practitioners have to assume that the knowledge on which they are going to act has some finality: "If we do this the lake water will be improved." Scientific researchers, on the other hand, think of scientific knowledge as never final: "If we take this action we may discover another whole set of circumstances about the water quality that we don't understand."

6. The conditions under which scientific practitioners operate do not allow manipulation of their environment to allow certainty about the variables involved in decisions: "We've got to find something to do about Clear Lake with the weeds, the swimmers, the boaters, and the septic tanks as they are." Research scientists, on the other hand, try to build experimental designs in which some factors can be controlled to allow variables to be studied and measured: "If you can just stop the effluent from all the septic tanks around the lake for three years, we can gain an understanding of what is happening to the weeds and sediment in the lake, and then we can understand what might be done about it."

It should be emphasized that while the differences in viewpoint between practitioner and researcher have been highly instructive in allowing university researchers and state agency staff members to deal with differences in their viewpoints, neither "practitioner" nor "researcher" completely applies to any group of individuals. These are models and not total characterizations.

To aid in the management objective of transfer of technology as a result of these research projects, attempts were made to help persons on the research side and the agency side learn the language and customs of the other, expect problems in the transfer, and expect to be able to solve the problems of transfer through working together. Dialogue was an important tool in this process. Tools used also included workshops, small group meetings, collaborative planning, collaborative data acquisition, site visits, temporary switching of roles, and cooperative work on manuals on the technology. Collaboration in preliminary planning before a research project commenced was found to be very important to aid transfer of technology.

III. CASES ILLUSTRATING PROBLEMS OF FLOW AND TRANSFER

A. Remote Sensing Research for Monitoring Eutrophic Level of Lakes

Researchers at the University of Wisconsin had been at work for several years developing means by which water quality parameters could be determined by remote sensing when the Department of Natural Resources (DNR) of the State of Wisconsin was faced with a critical application problem. The department was required to make an assessment of the eutrophic level of all lakes within the state having an area larger than 100 acres. The assessment of thousands of lakes by means of ground sampling seemed financially impractical. Suggestions that LANDSAT-1 or high-altitude aerial data be used for this assessment were met with reservations by staff of the Department of Natural Resources. Problems of resolution of LANDSAT-1 data and reliability of analysis seemed to provide good grounds for skepticism. When trial tests were made, however, a technique appeared possible. Research that was then designed to include close collaboration between researchers and users produced a useful technique. The DNR is already knowledgeable about this and is preparing to use its own interactive terminal for analysis of LANDSAT-1 data. Its own technicians will use the technology developed to monitor lake eutrophic levels.

1. What was done.- Staff members of the DNR having responsibility for planning and enforcement of water quality programs had been advisory members of the steering committee for a project on remote sensing for some time. They brought the problem of monitoring eutrophic levels of lakes as a possible goal for remote sensing research. In order to be sure that goals for research would be formulated in such a way that the questions answered would be clearly related to the questions as they face the DNR, the role of DNR staff members in the management of the remote sensing project was strengthened. DNR staff members became principal investigators along with university research personnel. As a result of this, they participated in deciding specific objectives for research each year, formulating the budget for the proposed research, deciding research sites and time schedules, supervising laboratory and field workers, contributing sections to interim and final reports, and discussing or clarifying final reports wherever they were presented. No attempt was made to have the roles of the university researchers and DNR researchers interchangeable. Rather, they were complementary to one another.

The specific work of principal investigators from the DNR and the university took place within a general dialogue between DNR staff and university researchers over what is possible in remote sensing. To initiate one phase of the dialogue a one-day workshop on current work on remote sensing was presented for personnel of the DNR. University staff did not know which people in the DNR would be interested. The management of the DNR canvassed their organization: About 30 of their staff members representing a wide variety of interests took part in the workshop.

University researchers led off each session with a brief description of the work in which they were presently engaged, leaving at least 50% of the time for free discussion. Some of those attending felt afterward that a longer time could have been spent on each topic, but experience indicates that the attempt to extend a familiarization session beyond one day produces diminishing returns.

In the course of the workshop,participants were urged to make arrangements to pursue specific questions by individual or small group arrangements on a more limited topic. One example of this occurred several months after the workshop when a small group met to discuss specifically what could be done through digital analysis of LANDSAT imagery of lakes to monitor eutrophic level. One university researcher had prepared a program for image analysis by means of an interactive computer terminal and arranged to explain the possibilities and limitations of this process to operating personnel of the DNR. This small-group,one-half day discussion,including demonstration,was focused clearly on further development of this particular piece of technology. Progress toward fulfilling the need of the DNR and areas in which greater development was needed became clear in the interaction within the small group. As a result of this meeting arrangements were made for refining the technique and for establishing a means by which employees of the DNR would develop proficiency in the use of this program. Although hired by the DNR they would work at the university under the supervision of a university researcher.

Finally, on the basis of experience of the DNR personnel who are developing competency in the use of this interactive program for assessing lake eutrophic level, instructions will be prepared by researchers bringing together theory and technique in a manner that will allow the DNR to use its own employees and its own interactive computer terminal to carry on a program of continued operation without reliance on university personnel. The manual will not only give instructions but will explain theory and limitations of the techniques in order that the DNR can be clearly aware of areas in which the application of the technique will be dependable.

2. Data and information flow.- While research on monitoring the eutrophic level of lakes has developed into a transfer of technology to the DNR, it has also involved data and information flow. Decisionmakers in the DNR needed to know the eutrophic level of each lake in the state as soon as possible. This problem was communicated across the (1)-(2) interface (see Figure 1) to university researchers in the course of general meetings of the Steering Committee of the research project and the workshop described in III.A. University researchers collaborating with DNR personnel analyzed the problem and defined the tasks of identifying lakes, analyzing density on LANDSAT-1 and RB-57 imagery, relating this to ground truth, and establishing a classification system. Data requests in this case went from university researchers to NASA for LANDSAT-1 and RB-57 imagery. The data were received for processing by the university and by DNR personnel. In this particular case, the data processing and the analysis and interpretation become intermingled since interface (3)-(2) involves an interactive computer program. After the lake to be studied has been identified on the digitized computer-compatible tape made from LANDSAT-1 or RB-57 imagery, the researcher viewing the image on a television screen is able to choose areas of the lake from which data samples will be taken to establish characteristic readings for the whole lake. This allows him to avoid idiosyncrasies in determining density readings from the area of the lake that might be caused by the large pixel size of LANDSAT-1 imagery or other conditions he can identify by viewing. In this process, he can also choose between different scanner bands of one image and images from different dates. By a series of questions and answers and of images, the data are refined and interpreted. The data and information flow sequence is finally completed when the eutrophic level is reported to the decision-making agency.

At two points the communication at an interface was more complicated than the simple diagram (Figure 1) indicates. Figure 3 illustrates the nature of the communication at the (1)-(2) interface in the formulation of this problem. The communication across interface 1-2A-2B has been stylized but it can be seen from the scheme depicted in Figure 3 that numerous elements of interactive communication back and forth across these interfaces are necessary before a problem is formulated clearly. At each point the university researchers or DNR staff members felt they were asking a clear question or making a clear statement. The need for elucidation each time they communicated across the interface made the attempts to communicate burdensome and made disengagement seem attractive. But with continuation of the communication, productive work was done. If communication difficulties at an interface appear to disable the data and information flow, greater concentration on dialogue--message and response or question and answer--may free communications and the data and information flow.

A diagram similar to Figure 3 could be drawn for the interface between (3) and (2) in the return of information for analysis and interpretation by means of the interactive computer program. A diagram of this communication would appear as a series of questions and answers, questions and clarifications across the interface (3)-(2) until the operator received the data that would be best used to characterize the eutrophic level of the lake. The operator would relate data received from imagery to data received from other sources during his interaction with the digitized data displayed by the computer terminal, before final interpretation was made. In research projects in which no computer interactive program is involved, this kind of interchange back and forth between data processors and analysts and interpreters may be necessary in order to clearly define the data.

3. Transfer of technology.- In this project, a technique was being developed that ultimately was transferred for use to the DNR. It can be assumed that all of the differences of viewpoint referred to in the previous section could potentially inhibit transfer of this technology. Here are some ways used to get around differences in viewpoint in several areas.

(a) Value systems: The primary emphasis to be expected of research personnel in this project would be an understanding of why differences in reflectance of water bodies would be related to the eutrophic level of the lake. The emphasis of DNR staff members would be to assure the development of a useful tool for establishing the eutrophic level. Because the agency staff members and researchers sit together in planning research and have equal voices on the steering committee for the project they are able to work out the implications of their different points of view about what is the most important product of the research. They have been able to maintain two emphases: (1) the development of a satisfactory technology within a reasonable time and (2) the understanding as fully as possible of the reflectance phenomena connected with eutrophication of lakes. These two emphases broaden the perspective of each group in work on the research.

(b) Uniqueness or generality of the result of research: University research personnel would like to develop a generalized theory of lake water quality while DNR personnel need to have specific categories of eutrophication established for each lake. It has generally been agreed in planning sessions and exchanges between principal investigators that the work to determine specific classifications of the lakes must go first, but at the same time generalized work on the dynamics of lake eutrophication need to be going on. Were it not for the emphasis given by DNR personnel in planning this research, it is possible that the result would have been a highly theoretical treatment of lake eutrophication that would never have been usable by the DNR.

(c) Time frame: Differences in time frame have been worked out by interaction between the principal investigators during the design and execution of the project. University researchers feel rushed and have to do things more quickly than they otherwise would. Were it not for the emphasis on getting a product fairly soon from the research it is possible that a technology developed might have come along too late to be useful in this specific problem.

(d) Manipulation of the environment: The extent to which the environment should be manipulated in order to isolate particular variables in the research has been resolved by

collaboration by the principal investigators planning and executing the research. It is probable that university researchers on their own would have relied more on work in test tanks where conditions can be arranged and manipulated to suit the needs of measurement. Application to specific bodies of water might have been left to personnel of the using agency. As a result of collaboration between the using agency and the university researchers, however, the researchers have gone as far as they are able in making measurements on existing water bodies as they occurred in the environment. It is expected that there will be a movement back and forth between actual field conditions and laboratory conditions as steps are made in the progress of the research. The technology that is being developed, however, is useful in lakes as they actually exist.

(e) Communication patterns: Differences in communication patterns between the researchers and science practitioners have influenced the form in which final results of the development of this technology will be published. Research results still will be submitted to journals for journal articles; in addition, in order to facilitate the transfer of technology, a user's manual is being prepared to explain the use of the technique, the training of personnel to use it, and limitations to be observed in its use. These matters ordinarily would not be covered in journal articles produced by university researchers. The production of a user's manual grew out of collaboration between DNR personnel and university personnel.

(f) The finality of knowledge: Differences in viewpoints over the finality of knowledge contained in the technology largely remain. University research personnel as a result of their collaboration with DNR personnel probably understand better the need of an operating agency for a technique that represents a solid answer to the problem. Yet university research personnel cannot abandon their dedication to the pursuit of knowledge and the understanding that tomorrow we will learn more and what we know now will possibly be obsolete. The continued skepticism of research personnel about how final their answers are will probably continue to bother the users of the technique, but greater understanding and appreciation of these two different viewpoints will probably reduce misunderstandings that might slow the transfer of technology.

B. Importance of Including Decisionmakers in Preproposal Planning of Research on the Regional Land Use Process

Strong negative attitudes toward the use of data from LANDSAT-1 for regional land use planning and toward the research process seeking to evaluate the potential use of the data were experienced in one project. This appeared to be attributable to the lack of opportunity for input from decisionmakers in the preproposal planning for the research.

As part of the research entitled "Evaluation of the Application of ERTS-1 Data to the Regional Land Use Planning Process," an advisory council was formed. The function of the advisory council, including county planners, regional planners, state planners, private planners, and other members of the planning community, was to interact with the project investigators to attempt to involve the land use data users in the evaluation of the application of the data generated from satellite and high-altitude aircraft for regional and state land use planning.

The advisory council met three times: the first for familiarization with the characteristics, capabilities, limitations of the LANDSAT system; the second and third for full-day workshops directed toward the evaluation in user terms of the research investigation. Some of the advisory council found in the investigation new potential uses of the LANDSAT-1 data, and approved the conclusions of the research. A few, however, felt that the investigation itself was not necessary, since it would have been clear from the beginning of the preproposal planning, had regional planners been involved at that point, that satellite data could not meet the needs of regional planners. The Assistant Director of a Wisconsin Regional Planning Commission wrote that since "in Wisconsin regional planning is local planning," the detail for local planning could not be secured from satellite imagery.[3] While there was not agreement to this idea, a generally agreed understanding of what was meant by "regional planning" was so basic to the research, that such a question should have been anticipated in the design of the research. Since there was not opportunity to include very much preproposal input from decisionmakers in the design of the research, a potential

problem in the project was not discovered until late in the work.

The Advisory Council member who took exception to the view of regional planning in this project suggested that "actual users of data to be derived from research programs at the University or operational programs at the state level be included in the structure preceding the actual operations of programs and specific studies in order that these users may provide input regarding specific needs."[4]

In this case the debate stimulated by this incident may have served to bring out more in the responses of potential users of remote sensing data than would have been seen if the opportunity for more preproposal planning had been present. Certainly NASA had gone far to try to include the planning community as users in the preparations for the LANDSAT research, but not all possible users could be involved.

For a university, approaching the planning of research related to the needs of governmental agencies, preproposal planning must include adequate input from the expected user agencies. Yet money is not readily available for this very important preproposal planning. Some mechanism must be found to support research planning in this phase if user-related research is to continue.

C. Meeting of the Minds in Preparation of Land Cover Maps

In a small research project in which difficulty had been experienced in the data and information flow process, a contract was used to clarify communication at the interface.

1. What was done.- When results of a research project on the use of LANDSAT-1 data for statewide land-use planning functions were presented to the decision-making organization, the results did not seem to answer the questions that had been proposed. Discussion of the problem afterward indicated that while there had been communication between the research staff and the decision-making agency, the two groups had not developed compatible understandings about the work involved. When a new project was being considered, the decision-makers and the researchers used a technique from the business world to clarify the understanding between them. A contract was drawn up clearly specifying the expected product from the research.

In this case, the decisionmakers were identical with the interpretation and analysis personnel. Their need was for land cover maps made from LANDSAT-1 imagery. Researchers were in the role of data processers. While it seems rather simple to write a contract clearly specifying that maps of a certain type will be delivered, the comparison of ideas and perceptions that went into the discussion of terms for a contract helped parties on each side of the interface to communicate and agree and to spot potential misunderstandings. If the preparation of a contract, however, is a perfunctory matter, it may not serve much useful purpose in clarifying the flow of data and information across the interface.

D. A Data Center in the Data and Information Flow Process

A Data Center, maintained to serve as a library for data acquired by several remote sensing projects and to make remote sensing data available to users, occupies a unique place in the data and information flow sequence.[5] In operation for several years, the Center makes available low altitude color and color infrared photography, thermal imagery, high-altitude RB-57 imagery, LANDSAT-1 70mm and 9" transparencies, and a 16mm Browse file of LANDSAT-1. Publications to support the imagery are also available. Announcements of the imagery available are mailed to potential users, and a catalog of imagery available is distributed.

If the Data Center is considered in relation to the diagram of data and information flow, Figure 1, several characteristics are suggested. User input into the data and information flow process is limited to "after the fact" input--the data have already been acquired and are waiting there. They cannot be changed to respond to the potential user's needs. This may be expected to produce lower credibility than would data from a process

into which the user had input. But this may be balanced by another factor: the data can be compared with other data from different sources. This gives a degree of discretion to the user, and may help credibility.

In the case of the Data Center, the question of communication among the roles represented in the data and information flow may be different from the diagram in Figure 1, depending on the role of the potential user. Figure 4 is a revision of the diagram in Figure 1, to indicate two special cases of communication. The person looking at data in the Data Center is looking across the interface toward the (4) Data Acquisition role. But this person may be (1) a Decisionmaker, (2) an Analyst or Interpreter, or (3) a Data Processor. If he is a Data Processor, the flow of data should be the same as in the simple case shown in Figure 1. If he is in the role of an Analyst or Interpreter he may not directly make sense out of data. Processing probably is needed. In the operation of the Data Center, users who need help in understanding the imagery are sometimes given help by researchers in remote sensing. This is a way of filling the need for a Data Processor in the data and information flow. The path of communication is on the curved line by-passing the Data Processing role with the assistance of a person brought in to help the user.

A practice adopted by the Data Center to represent the data in lay rather than technical terms, indicates another special communication problem. To help lay persons, site names were assigned and an "industry category" created to permit access to the collections by the type of problem being studied. (For example, in a cross-reference section of the card catalog, film of power plant effluents are grouped together, algae blooms are grouped together, and paper mill effluents are grouped together.) This is an attempt, from the point of view of the data and information flow, to aid a (1) decisionmaker in communicating across the (2) Analysis and Interpretation and (3) Data Processing roles, shown by a curved line on Figure 4. It would seem to be important that in this case, adequate supplementary help be available to allow the decisionmaker to be able to encompass the whole data and information flow process in one move, while several distinct moves are ordinarily needed.

A final question about the place of the Data Center in the process is related to the proposal that a survey be made to seek from users an indication of their needs. In this case, is the Data Center in the role of Data Acquisition (4), asking users as though they were (3) Data Processors, and (2) Analysts and Interpreters, and (1) Decisionmakers? These roles probably must be kept separate in the survey questions--with the normal role of the potential user identified--in order that the questions may presuppose the right context. But in asking the questions the Data Center may be functioning as a combination of (4) Data Acquisition and (3) Data Processor, seeking information from primarily (2) Analysis and Interpretion, but needing another step, interpretation, to allow open communication with (1) Decisionmakers. This illustrates the special problem of the Data Center Survey: It represents a particular case in which the distinctions in role in the data and information flow must be clearly understood, since the meaning of questions and answers will depend upon which interface the communication is assumed to involve.

IV. CONCLUSION

If a necessary result of research is useful technology or useful information available to decisionmakers in governmental agencies, this result will be most likely to develop if objectives of the research from the beginning of the planning include the flow of information or the transfer of technology. This adds a dimension to what scientists would call "pure" research, requiring of the researchers and the potential users not only scientific clarity, but skill in "extra-ordinary" communication. Such ability is distributed no more equally among individuals than is scientific skill.

Some tools of communication, such as meetings or reports, may not be valued by scientists because these tools are common to nonscientific, everyday enterprises where their functions are blurred and their execution often is inept. This negative appraisal may lead to reluctance to use such tools, even when they are necessary.

To include in a research project the dimension of relevance to decisionmaking, objectives and specific tasks should be designed to call attention to the need for communication as part of the process of research. Aids should be available to supplement the communication skills of researchers and decisionmakers. Time schedules should allow participants in the research to withhold their judgements of what is being communicated, or whether communication is successful, long enough for the dialogue necessary at crucial points to mature (See Figure 3). Finally, participants in the research and decision-making aspects of this enterprise must be helped to expect success in finding the relationships between research and use wherever there are possibilities for such a connection.

NOTES

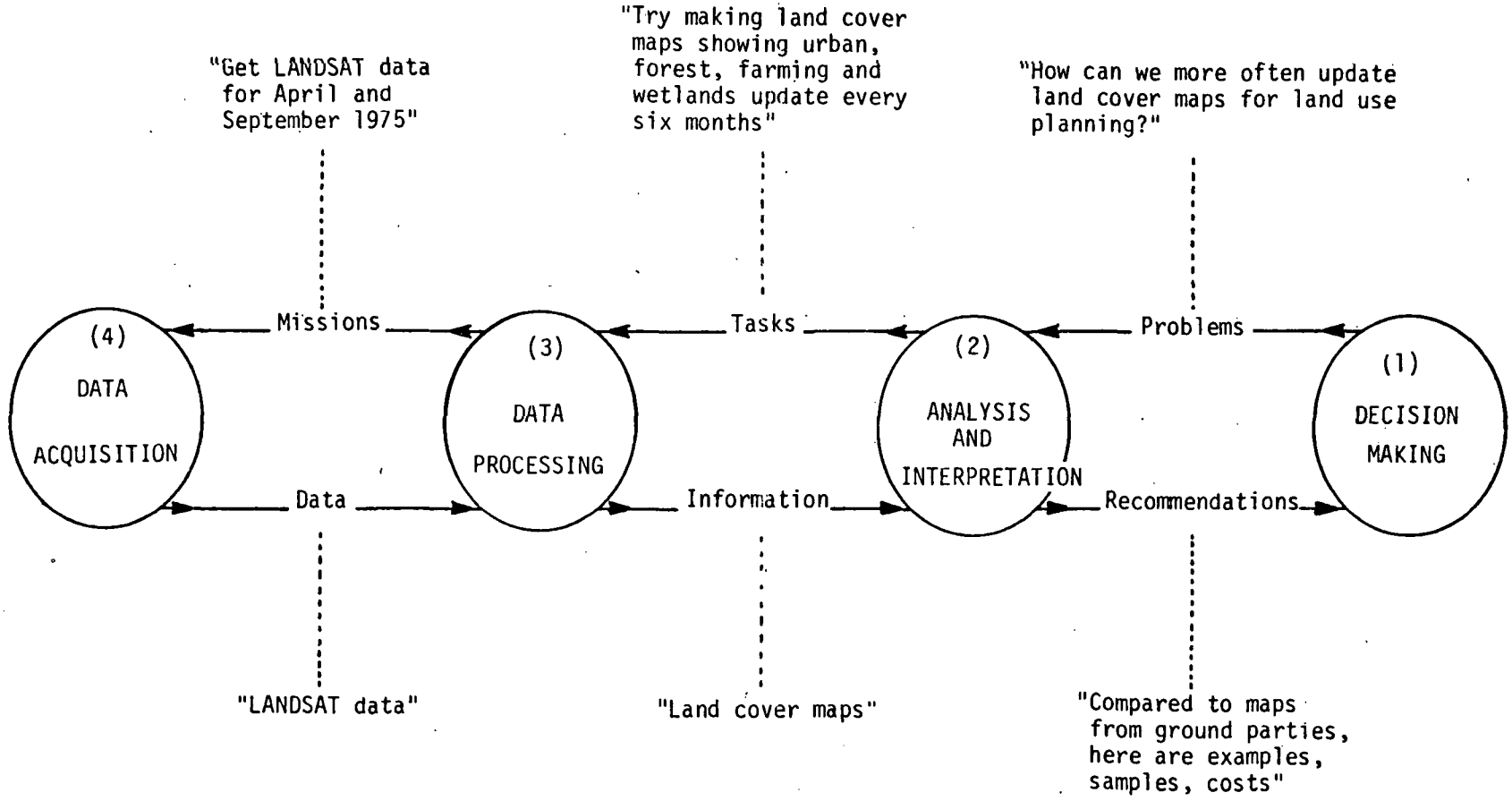
1. Adapted from Arnold Lanckton, "Remote Sensing: International Market and Market Trends," presented at Conference of Institute for Graphic Communications, Ipswich, Mass., October 1973.

2. James P. McNaul, "Relations Between Researchers and Practitioners," in The Social Contexts of Research, eds., S. Nagi and R. Corwin (New York: Wiley-Interscience, 1972).

3. James L. Clapp, "Evaluation of the Application of ERTS-1 Data to the Regional Land Use Planning Process," Final Report, prepared for the National Aeronautics and Space Administration, 23 October 1974, pp. 269-279. Contract number NAS5-21754.

4. Ibid.

5. The basic material on the Institute for Environmental Studies Data Center upon which this interpretation of processes in the Data Center was based, was furnished by Barbara Kenny, Data Coordinator.



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Figure 1. Diagram of data and information flow showing four distinct roles and communication across the interfaces between them. Adapted from Arnold H. Lanckton, "Remote Sensing: International Market and Market Trends," presented at Conference of Remote Sensing, Institute for Graphic Communications, Ipswich, Mass., October 1973.

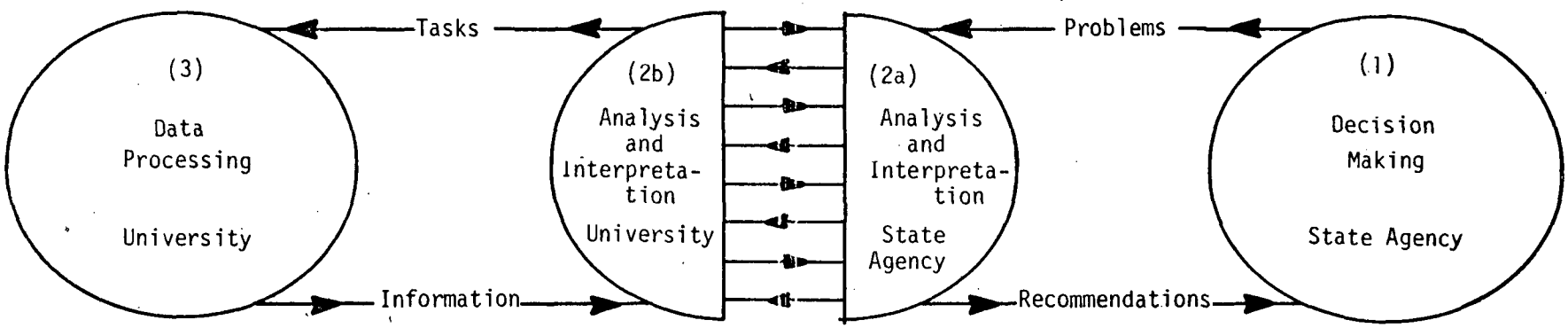


Figure 2. Detailed section of diagram of flow of data and information showing relation between state agency staff members and university research personnel when both are involved in the role of analysis and interpretation.

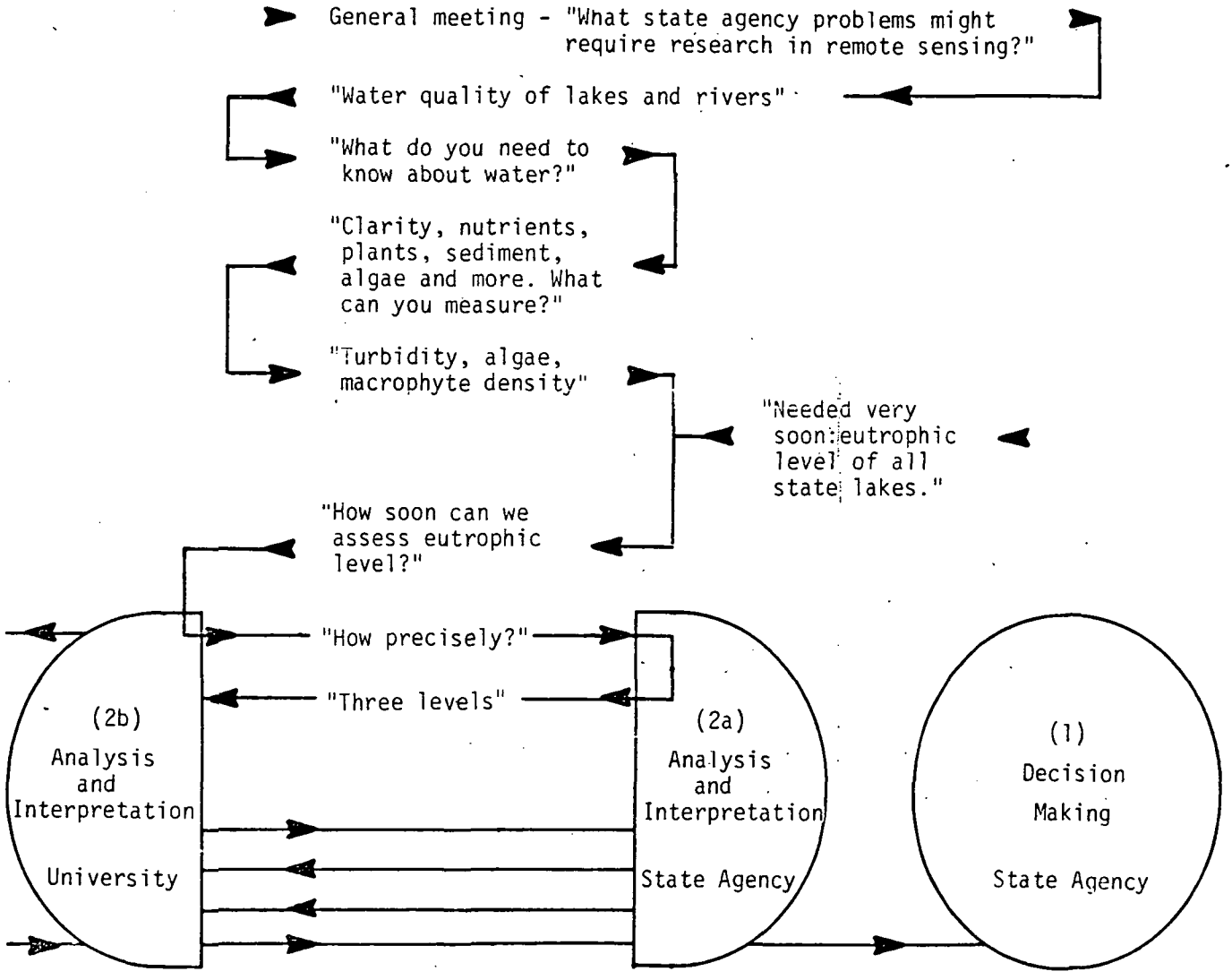


Figure 3. Detail of section of Figure 2, diagram of data and information flow, showing typical steps in the communication across the (1 - 2a) and (2a - 2b) interfaces.

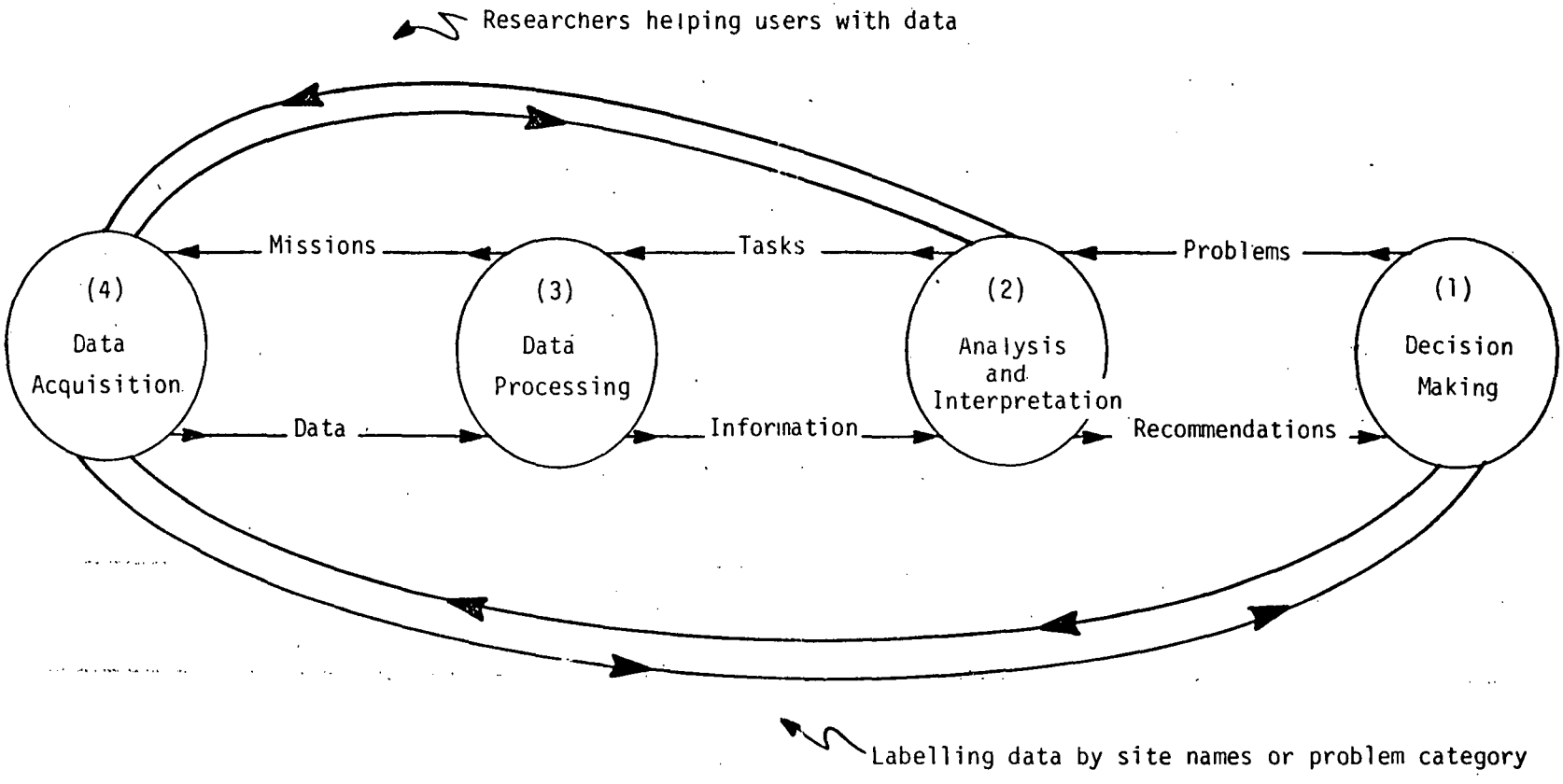


Figure 4. Diagram of data and information flow revised from Figure 1, illustrating the addition of research personnel and the use of lay-oriented labelling to complete process of information flow in a Data Center.

THE DEVELOPMENT OF A LAND USE INVENTORY FOR REGIONAL PLANNING USING SATELLITE IMAGERY

L-10

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ABSTRACT

Under provisions of Section 208 of the Federal Water Pollution Control Act Amendments of 1972, the Ohio-Kentucky-Indiana Regional Council of Governments (OKI) received a grant of $1.9 million for water quality planning for a nine county area centered around Cincinnati, Ohio. Similar grants have been made by the U. S. Environmental Protection Agency to councils of government in other metropolitan areas. The purpose of 208 water quality planning is to identify all sources of water pollution in major urban-industrial concentrations and to develop effective programs to reduce such pollution. The planning process includes not only a study of public sewerage systems and industrial pollution, but also an analysis of agricultural and urban stormwater runoff. Because water quality is in large part determined by land use activities and patterns, detailed up-to-date land use data is needed. Traditional land use inventory techniques are too time consuming. Land use data generated by computer processing of satellite imagery offers a viable alternative for obtaining the needed information. This report explains the need for land use data for water quality planning, problems which might be encountered in the use of satellite imagery, and the generally favorable results obtained by OKI.

INTRODUCTION

The Federal Water Pollution Control Act Amendments of 1972 (PL 92-500) created several programs to fight water pollution. Under provisions of Section 208 of that act, regional councils of government such as OKI were given the opportunity and the funding to undertake regional water quality planning. Before beginning the discussion of OKI's experience in the use of a land use inventory generated through computer processing LANDSAT-1 digital tapes in the water quality planning process, it would be useful first to take a look at regional planning in general, the present level of regional planning activity in this country, and water quality planning in particular.

REGIONAL PLANNING

Regional Planning was born out of a realization that many of the problems and opportunities which face local government, particularly in metropolitan areas, cannot be met individually be each county, city, village and township. These problems and opportunities cover a wide range of public concern, and include such things as highways, mass transit, housing, health services, parks and recreation, water supply, solid waste, air quality, sewage disposal and coastal zone management. These are problems that do not respect political boundaries which, in most cases, were chosen long ago and without regard to the efficient and adequate provision of public services. For example, in the ten county OKI region (only nine counties are participating in the water quality program) centered around Cincinnati there are 128 municipalities, 81 townships and an even larger number of special districts. Regional councils of government, such as OKI, were created in the belief that communities should be able to achieve

through collective action the goals that none can achieve alone.

As of July 1, 1971, there were 247 Standard Metropolitan Statistical Areas in the United States, each centered around a central city of 50,000 or more population. Most have a regional council of governments or regional planning authority. In addition, most states have broken down their area into sub-state multi-county planning districts with councils of governments. According to the 1974 Regional Council Directory published by the National Association of Regional Councils, there are over 600 councils of governments in the United States.

Each has undertaken planning activities in various functional areas to one degree or another. OKI, for example, has completed an overall development plan, as well as plans for highways, housing, open space, water supply, sewage disposal and solid waste. Currently, the OKI staff is working on a mass transit plan and a water quality plan as well as updating other plans.

Because satellite imagery is furnished by NASA for scenes covering a rather large area and because of other economies of scale inherent in the interpretative process, the development of a land use inventory from satellite imagery is most practical if done at a fairly large scale. Regional planning areas fall within the scale, and regional councils of governments are an obvious and substantial market for the use of data generated from satellite imagery.

WATER QUALITY PLANNING

OKI was one of the first regional councils of governments to receive a grant from the U. S. EPA for 208 regional water quality planning. At present, some 45 agencies have either begun work on 208 plans or have been assured of EPA funding. As many as 100 additional agencies will be funded before the end of the current fiscal year. The new 208 program differs from past HUD-financed water and sewer planning in that this new EPA-administered program deals with all sources of water pollution, not just pollution from municipal sewerage systems. Other sources of water pollution for which planning responsibility is given are industrial discharges and what are termed "non-point" sources. These non-point sources include sedimentation and runoff of pesticides and fertilizers from agricultural areas, urban runoff, erosion from construction sites, and leachates from septic tanks.

THE LAND USE ELEMENT OF WATER QUALITY PLANNING

A major task of the 208 planning program is the prediction of water quality in the rivers and lakes resulting from existing and future land uses. This will lead to the formulation of new land use policies which reflect the need to improve water quality. To achieve this, OKI has developed a model capable of predicting sediment and nutrient flow into the waterways of the region. An essential input to the model is an accurate map of land use. OKI needs to know how much acreage of each land use type is within each of 225 drainage areas within the study area. Other variables include slope and soil type.

Each land use type has a special characteristic which is important in the calculation of the quantity and quality of stormwater runoff. For example, land used for growing crops is often tilled in the spring when rainfall is heaviest. Much of the rainfall is absorbed into the earth, but erosion can be significant under such circumstances, resulting in

sedimentation in nearby streams. Pesticides and fertilizer substances may also be washed into the stream. This differs from what happens in a central city area where virtually all of the ground is covered by pavement and buildings. Little or none of the water is absorbed into the earth. Instead, it flows rapidly into storm sewers, carrying with it dirt from streets and buildings.

The relationship of land use planning to water quality planning, then, becomes quite obvious. The inventory of present land use together with population projections will serve as a basis for developing a future land use map. Given future land use, the water quality model will be run again to determine the impact of future development on water quality. This analysis will lead to an identification of critical areas, areas where alternatives will have to be developed to minimize any deleterious impact on water quality. This may involve redirecting growth to other areas where the impact might not be so severe or changing the character of the growth to minimize any harmful impact on water quality. The water quality plan will, in effect, contain a significant land use planning element. The 208 water quality planning program may provide the most rational basis for land use planning available to date.

Because the 208 program involves planning agencies in a type of planning with which they have not previously dealt, new data systems must be developed. This is particularly true in regard to land use data.

Land use information currently available to planning agencies is generally not adequate for water quality planning purposes. In almost every case, agricultural forest and vacant land has been lumped into one category-miscellaneous, and urban land uses often are not identified in terms usable for water quality planning. Often, the data is not current, not consistent for the entire study area or not capable of being tabulated by drainage area. Therefore, new region-wide land use inventories are needed.

The OKI Region, like most regional planning areas, is fairly large. It covers 2700 square miles. For this reason, the traditional techniques for land use inventory - field inspection and manual interpretation of aerial photographs - were judged to be impractical in that they are too costly and more importantly, too time consuming. Time is critical because the water quality program is only a two year effort, and a land use inventory is an input which is needed very early in the program. Given this need to produce a land use inventory in the shortest possible time, the OKI staff looked for and found a much faster method - the use of satellite imagery.

THE DECISION TO USE SATELLITE IMAGERY

None of the OKI staff had any experience with satellite imagery. The staff first heard about the potential applications of satellite imagery in regional planning at the annual meeting of the American Institute of Planners in October, 1974. Subsequently, representatives of various private firms which market the interpretation of satellite imagery as a service met with the OKI staff. Examples of data and visual aids from previous studies convinced the staff that a satisfactory land use inventory could be obtained. Most impressive of all was the fact that the resultant data is very detailed both in terms of the categories which can be identified and in that the dominant land use can be determined for each 1.12 acre cell or "pixel". Also the data can be displayed in a visually attractive format with color coded acetate overlays or a color coded composite map. This is important to public agencies such as OKI which are committed to public involvement in their planning programs. Another major advantage of this technique is that

the interpreted images are already computerized and the data can be summarized by county, drainage basin or other statistical unit.

The next step was to obtain approval from the OKI Executive Committee (OKI's governing body composed mainly of elected officials) that the expenditure would be a wise one. The staff had earlier estimated the cost of generating a land use inventory using traditional techniques of aerial photo interpretation and field inventory. Therefore, the staff was able to show that a land use inventory generated from computer processed satellite imagery would not only be comparable in terms of cost, and possibly even lower, but that a significant savings in time could be achieved, possibly as much as six months. Based on this information, the OKI Executive Committee unanimously agreed to approve the use of satellite imagery.

The U. S. Environmental Protection Agency requires that OKI obtain its approval before entering into any contract exceeding $2,500. After a reasonable review period, EPA approved OKI's contract with the Bendix Aerospace System Division without revision.

THE RESULTS

The final product is a 10 - category land use map of the OKI Region at a scale of 1" = 5000' showing the following land use activities: grassland, idle cropland, active cropland, water, two categories of forest land, and four densities of urban development defined in terms of the percent of ground covered by pavement and buildings. In addition to a composite map, OKI also received separate acetate overlays for each land use category. Since these overlays are reproducible, they are particularly useful as work maps.

OKI's experience in the development of a land use inventory has been a successful one. The total acreage for each drainage area as measured from the satellite data matched very closely the acreage measured by using a planimeter. Field checks and interviews with farmers and agricultural agents have shown that the categorization has been accurate within a reasonable level of tolerance.

OKI has also learned more about the limitations of such data and problems which might be encountered in generating this information. For example, even though the two LANDSAT satellites now circling the globe each pass over the OKI Region once every eighteen days, it was necessary to use LANDSAT images from April 14, 1973, because none of the more current images were taken on cloudless days. While a 1973 image is quite acceptable, and certainly more up-to-date than anything otherwise available, one should not count on using images taken last week, for example.

Also, delays can be expected in obtaining the LANDSAT-1 tapes from NASA. It may take as much as a month. This delay can be embarrassing if promises of delivery of the final product have been made to local planners, committees, or other interested parties.

Then, too, the data itself may require some manual interpretation. For example, the data received by OKI presented the acreage for cropland as significantly less than that identified in various agricultural surveys. After some investigation, it was discovered that the cropland category only included row crops such as corn and soybeans, and not wheat or alfalfa which were shown as part of the grassland category. Other problems were encountered because unrelated land uses were found to have the same spectral characteristics.

OKI was, however, able to overcome these difficulties through manual interpretation and division of certain land use categories. It was found that the categories can be more accurately defined through the use of more detailed ground truth data.

CONCLUSION

The OKI project has clearly shown an important practical application of LANDSAT data. Indications are that our success has already encouraged several of the other existing and potential water quality planning agencies to consider the use of LANDSAT generated data. Furthermore, the planning applications need not be limited to water quality analysis. As the interpretative process becomes more sophisticated and as planners become more aware of the potential uses of such data, the scope of its use will undoubtedly expand to include other environmental planning activities. For example, satellite imagery may be the best way to monitor suburbanization or land absorption. The extent to which satellite imagery and related services will be used for regional planning in the future may depend upon improved communications and the establishment of a closer working relationship between the users and the researchers.

REFERENCES

National Association of Regional Councils, "1974 Council Directory", Washington, D. C., July, 1974.

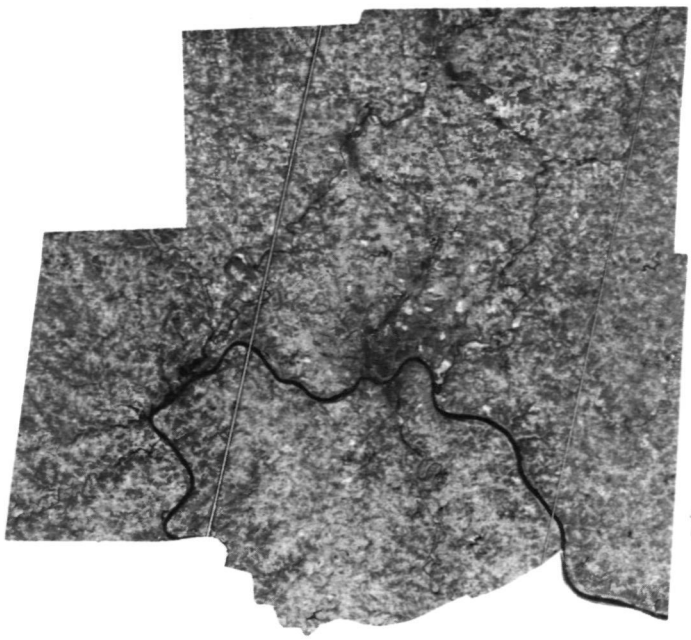
Ohio-Kentucky-Indiana Regional Council of Governments, "Clean Water: What You Can Do", Cincinnati, Ohio, October, 1974.

Ohio-Kentucky-Indiana Regional Council of Governments, "What's It All About?" Cincinnati, Ohio, January, 1975.

R. H. Rogers, C. L. Wilson, L. E. Reed, N. J. Shah, R. Akeley, T. G. Mara, V. Elliott Smith, "Environmental Monitoring from Spacecraft Data", Symposium on Machine Processing of Remotely Sensed Data, at Purdue University, West Lafayette, Indiana, June, 1975.

U. S. Environmental Protection Agency, Office of Air and Water Programs, EPA-430/9-73-014, "Methods for Identification and Evaluation of the Nature and Extent of Non-Point Sources of Pollutants," October, 1973.

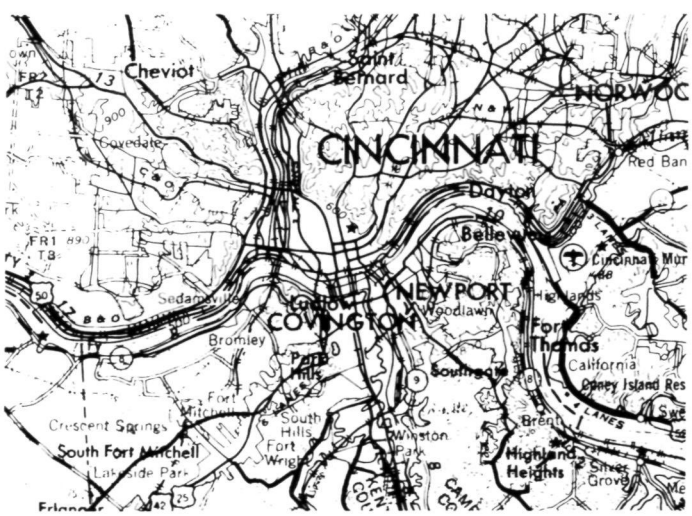
U. S. Environmental Protection Agency, Water Planning Division, (Draft) "Guidelines for Areawide Waste Water Treatment Management," May, 1974.



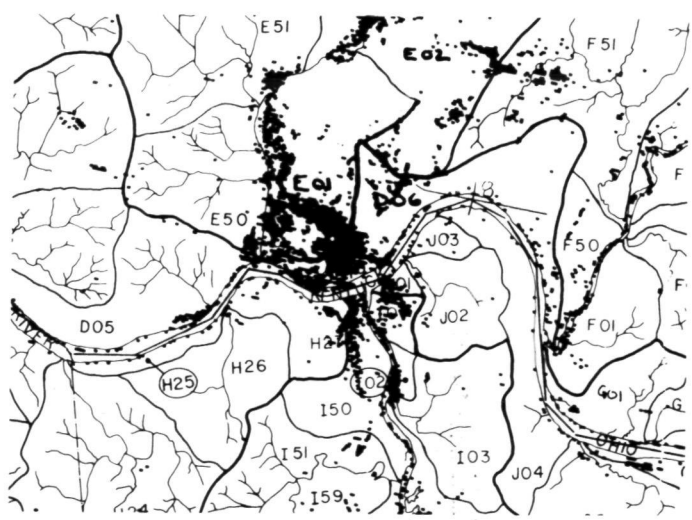
LANDSAT-1 BAND 7 IMAGE
OF APRIL 14, 1973 SHOWING
THE OKI REGION



COUNTIES AND MAJOR
RIVERS
OF THE OKI REGION



MAP OF PORTION OF THE
OKI REGION NEAR CINCINNATI



CORE CITY/INDUSTRIAL
CATEGORY OVER WATERSHED MAP

LUMIS – A LAND USE MANAGEMENT INFORMATION SYSTEM FOR URBAN PLANNING

L-11

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ABSTRACT

The Land Use Management Information System (LUMIS) consists of a methodology of compiling land use maps by means of air photo interpretation techniques, digitizing these and other maps into machine-readable form, and numerically overlaying these various maps in two computer software routines to provide land use and natural resource data files referenced to the individual census block. The two computer routines are the Polygon Intersection Overlay System (PIOS) and an interactive graphics APL program. A block referenced file of land use, natural resources, geology, elevation, slope, and fault-line items has been created and supplied to the Los Angeles Department of City Planning for the City's portion of the Santa Monica Mountains. In addition, the interactive system contains one hundred and seventy-three socio-economic data items created by merging the Third Count U.S. Census Bureau tapes and the Los Angeles County Secured Assessor File. This data can be graphically displayed for each and every block, block group, or tract for six test tracts in Woodland Hills, California. Other benefits of LUMIS are the knowledge of air photo availability, flight pattern coverage and frequencies, and private photogrammetry companies flying Southern California, as well as a formal Delphi study of relevant land use informational needs in the Santa Monicas.

INTRODUCTION

The Santa Monica Mountains of Los Angeles are a natural buffer between the developing Beverly Hills – Bel Air communities on the south and the San Fernando Valley on the north. They act as recreational open spaces to eight million people in the Los Angeles Basin. The City of Los Angeles traditionally proposes land uses by assessing and mapping socio-economic variables including population, housing, and parcel-level land use. Since the Santa Monicas encompass large areas of natural features as yet undeveloped, the idea of applying remote sensing to an existing geographic information system was born.

USER ADVISORY COMMITTEE AND TECHNICAL SUBCOMMITTEE

In order to make a thorough assessment of land use informational needs in the Santa Monica Mountains, a committee of prominent political officials actively involved in land use planning in Southern California was organized. This User Advisory Committee has been informed of every developing aspect of the LUMIS program. In addition, these officials have designated at least one, and in some cases three, members of their working staff to work directly with the LUMIS staff in formulating land use informational needs in the Santa Monicas. This working group is designated the Technical Subcommittee. The User Advisory Committee and the Technical Subcommittee agencies represented are the Jet Propulsion Laboratory, the Los Angeles Department of City Planning, the Southern California Association of Governments, the Community Analysis Bureau, the City Administrative Office, the Regional Planning Commission, the California State Office of Planning and Research, the State Department of Transportation, the State Water Resources Control Board, State Parks and Recreation, State Mines and Geology, Department of Water Resources, Cal Poly (Pomona), UCLA, and UC Riverside.

The first User Advisory meeting was convened on June 12, 1974, at the Jet Propulsion Laboratory. This meeting was well attended and resulted in a large number of responses in the ensuing Delphi study.

LUMIS NEWSLETTER

For purposes of informing the User Advisory Committee and selected land use planning officials of LUMIS developments, a monthly newsletter was initiated in May, 1974. An original list of approximately 225 officials was compiled for the Newsletter distribution. It was decided to add names to the list only for those respondents who requested such in writing; i.e., to let knowledge of the LUMIS Newsletter availability spread by "word of mouth" or by the official on the original list circulating the Newsletter among his staff. It was also decided to let normal attrition take its course; i.e., if an addressee on the list moved without informing the LUMIS staff in writing of his new address and a Newsletter addressed to him was returned, he was removed from the list. From May, 1974, to May, 1975, the LUMIS Newsletter distribution list grew from 225 to over 500 people. In addition to land use planning officials, the list includes virtually all land use remote sensing specialists, land use data base management analysts, and photogrammetrists in the United States, and many outside of the country.

The Newsletters were considered a valuable contribution to the LUMIS task for the following three reasons:

1. They allowed monthly dissemination of LUMIS developments to a wide range of potential future users of this or a similar system. This dissemination has prompted several planning agencies to take action to obtain LUMIS software from the City of Los Angeles. The Newsletters also illustrate the evolving plans for LUMIS; the problems, changes in concepts, and personnel contacts are clearly stated.
2. The Newsletters prompted scores of letters from planners and researchers developing similar systems. These letters contributed to an overall knowledge of land use information systems state-of-the-art by LUMIS staff and permitted them to redesign LUMIS software in more optimal ways than previously conceived.
3. The Newsletters comprised the best documentation of the LUMIS task, thus allowing a final report to be more easily written.

DELPHI LAND USE NEEDS STUDY

The Delphi land use needs study for the Santa Monica Mountains was carried out in three phases. The first phase identified 164 possible relevant land use types to consider incorporating into the LUMIS inventory. The second phase consisted of an importance ranking of these 164 items by the Advisory Committees. The third phase ranked these items again with the members having knowledge of the scores obtained on the second phase. The third phase reduced from 164 to 74 the land use data items considered in LUMIS (ref. 1).

In this Delphi study, members of the Advisory Committees were queried successively over several months in a procedure characterized by (ref. 2) anonymity of respondent, and involving interactive feedback between the LUMIS staff and the Committees to obtain a convergent consensus of relevant data items to be collected for the Mountains. The reader interested in more details of the technique employed in the LUMIS task is advised to consult reference 1.

Table 1 summarizes the main land use category ranking scores. The table shows the number of Advisory Committee members voting at three levels of importance for various broad level land use categories in the Santa Monica Mountains. It should be remarked that each of the three importance levels were broken into three sublevels, and each of the generalized land use categories were broken into from three to twenty subcategories, so that Table 1 represents averages across both dimensions of the matrix. However, the

voting ran fairly consistent across both the subcategories and the levels allowing the major groupings in Table 1. An interesting aspect of this study revealed in Table 1 is the convergence of this final polling relative to earlier phases of the study.

It should be pointed out that although the LUMIS task takes in the City's portion of the Santa Monicas, the study area also includes a full ten percent of the entire San Fernando Valley, and portions of Hollywood, West Los Angeles, Westwood, Bel Air, Brentwood, Santa Monica, and Pacific Palisades. Thus, the first nine land use categories in Table 1 (from Residential through Public Facilities) taken from the Standard Land Use Code were included in this inventory. The remaining categories were selected by the LUMIS Advisory Committees as part of the Delphi process. In order to effectively plan developmental and conservational elements in the Santa Monicas, it was considered important to include the overlapping communities between the Mountains and the heavily urbanized regions of the City.

Rather surprising to the LUMIS staff is the relative unimportance placed by the Advisory Committees on trade and service facilities. This may stem from past exclusionary zoning of these facilities in the Mountains. The lack of importance placed on manufacturing, agriculture, and mining likely stems from the almost complete absence of these land uses in the study area.

In the natural resource categories the lack of relevance associated with physiography, wild life, and aesthetics probably stems from the nebulosity associated with the definition of some of the items in these categories. Apparently there is also a lack of appreciation for the potential fire hazard associated with dry chaparral stands and other vegetation in the Mountains. It is also interesting that one Advisory Committee member who voted on the first nine cultural items elected not to vote at all on the physical resources.

AERIAL PHOTOGRAPHS

As requirements for land use types and data accuracies were being obtained by the Delphi study, a simultaneous search and interview procedure was conducted among various photogrammetric companies and engineering agencies to evaluate the quality, geographic coverage patterns, and frequencies of coverage for all of the Los Angeles Basin including the Santa Monicas. The results of this search are presented in ref. 3. Surprisingly, all of Los Angeles County is flown at scales of from 1:12,000 to 1:48,000 by various companies every year. The interpretation of Santa Monica Mountain photography for the years 1970, 1972, and 1974 was performed by Cornell University.

Reference 3 listed a table (Appendix III) indicating nine agencies possessing aerial photos for southern California. The photo variables included film format, scale, resolution, vignetting, exposure, form (positives, negatives, transparencies, prints), camera orientation (vertical or oblique), camera type, filters used, date and time, altitude, coverage (flight lines), overlap for stereo coverage, photogrammetric controls, indexing, geographical area covered, and cost of photos. Appendix IV of reference 3 listed eighteen agencies and companies and their land use activities involving air photos. Appendix V of reference 3 revealed the pattern and frequency of air photo coverage of various geographical regions of southern California and which photogrammetric companies are most likely to fly those areas in the future.

From the results of reference 3, the largest users of aerial photography in Southern California, i.e., Caltrans, the Community Analysis Bureau, Regional Planning, the County Engineer, Water Resources, UC Riverside, and VTN, Associates, all employ a great variety of cameras and film types depending upon the applications of each agency type. Black and white film tends to be used for larger scale, general reconnaissance or planning purposes with color infrared employed for smaller scale, environmental quality investigations; 9" × 9" format film still prevails. The RC cameras are the most favored. Most agencies are flexible in providing positive and negative prints or transparencies. Profit-making photogrammetric companies usually supply only positive prints or transparencies.

Most agencies fly only their areas of jurisdiction – for general planning they tend to minimize overlap for stereo purposes and ignore photogrammetric ground control. Thus with thirty percent or less of both side and end lap, precise orthophotos are available for only 20 percent of the coverage area. In contrast, photogrammetric companies flying for private developers and engineers requiring accurate map products will provide 50 to 60 percent overlap with ground-surveyed control points. Photos generally cost from $7 to $12 for small quantities – the price can drop to as low as $1 each for large batches (several hundred).

Although the uses of air photos depend to a great extent on the agency's area of interest and concern, reference 3 reveals the growing application of remote sensing in land use planning, environmental impact reporting, and transportation studies. Two very active civil engineering consulting companies, Dames and Moore and DMJM, are using air photos for environmental impact monitoring and resource analysis. CUNY (City University of New York) is attempting to link various data bases via remote sensing; a similar attempt to define census tracts from LANDSAT imagery by James Wray of the U.S. Geological Survey has met with partial success.

In terms of frequency, aerial photography covering the entire Southern California area has been taken by two or more firms. This coverage includes Los Angeles and Orange counties as well as Ventura County, San Diego and San Bernardino counties on a yearly basis since 1967. According to the management of most of the firms represented in this report, this trend will continue for many years to come.

AIR PHOTO INTERPRETATION

Land use maps were drawn for a 14-tract pilot area in the northwest corner of the Santa Monica Mountain project area from the three sets of photography employed in the project; i.e., sets for 1970, 1972, and 1974. The air photo interpretation and map compilation were performed early in the task to understand the magnitudes of relief displacement errors on the aerial photos. The 14-tract pilot area comprises very rugged terrain, with elevations ranging from 800 to 1500 feet. Even with the relatively small scale (1:48,000) photography used for the 1970 and 1972 land use maps, relief displacements of several hundred feet exist in the more rugged terrain of the Woodland Hills area of the City.

The aerial photos used in the LUMIS project were previously flown for general planning purposes by several Los Angeles City agencies. Since the coverage was not designed for photogrammetric control, only about ten percent sidelap and overlap exist for the stereo coverage of the photos. For this reason an orthophoto for the entire mountain range could not accurately be constructed since the center sixty percent of the area on each photo cannot be viewed stereoscopically. However, the overlap and endlap were sufficient to construct a photomosaic from the 1972 photos. This mosaic was available to the Cornell University interpretation team and was used by them to physically displace each land use boundary from its apparent geographic position on the individual photo to its true geographic position as evidenced on the mosaic. The photomosaics (two duplicate positives were made from the 1972 imagery) were constructed to rigid specifications and checked by the LUMIS staff by overlaying the final photomosaic transparent negative over the corresponding U.S. Geological Survey 7-1/2-minute quadrangle maps of the same area.

Since the photomosaic was not yet available when the first land use maps of the Woodland Hills pilot area were made, a simple and cheap method was devised to allow for relief displacement. This method will work for elevation ranges of one-thousand feet on a 1:36,000 to 1:48,000 scale 9-inch aerial photograph. In this method, one chooses several points (seven of these control points were used for the pilot area) which can be identified on both an air photo stereo pair and the U.S.G.S. quad map. These points are generally small street intersections and well defined building corners, all points at elevations covering the range of elevations encountered on the photo. These control points were carefully and precisely punched with a fine needle point while observing the pair of

conjugate points with a pocket stereoscope. The State Plane Coordinates (SPC's, California, Zone 7) of the control points were then calculated in the following manner. Please see figure 1.

The control point in the quad map was bracketed by 2-1/2-minute latitude and longitude grid tics. It is suggested that the SPC tics on the topo map margins not be used in determining the control point SPC's for two reasons: (1) there is an insufficient number of these tics to establish a dependable grid on the topo map, especially when considering that (2) the SPC grid will not be linear on the topo map projection.

The SPC's for the 2-1/2-minute intersection tics were obtained from the U.S. Coast and Geodetic Survey Plane Coordinate Intersection Tables (2-1/2-minute), SP-327, a copy of which can be obtained from the Superintendent of Documents. Thus the SPC's of the bounding lat-long tic marks were known and were designated (X_1, Y_1), (X_2, Y_2), (X_3, Y_3), and (X_4, Y_4) for the southwest, southeast, northwest, and northeast tics respectively. See Figure 2. Since the SPC's form a curvilinear coordinate system on the topo map, a 4-way linear interpretation for the X and Y coordinates of control point 1 was performed.

The grid tics around the control point were connected with a straight edge and a hard lead (4H) pencil. A perpendicular north-south line was constructed through the control point to the bottom and top grid lines. Since the scale of the topo map is 1:24,000, or 1" = 2000', the 20 scale of an engineer's scale (not architect's) was used to measure the units of x_1, x_2, y_1, y_2. Then the four solutions for each of the X and Y coordinates of the control point were calculated by:

$$X = X_1 + 1000x_1 + \frac{y_1}{y_1 + y_2}(X_3 - X_1)$$

$$X = X_3 + 1000x_1 - \frac{y_2}{y_1 + y_2}(X_3 - X_1)$$

$$X = X_2 - 1000x_2 + \frac{y_1}{y_1 + y_2}(X_4 - X_2)$$

$$X = X_4 - 1000x_2 - \frac{y_2}{y_1 + y_2}(X_4 - X_2) \qquad (1)$$

$$Y = Y_1 + 1000y_1 - \frac{x_1}{x_1 + x_2}(Y_1 - Y_2)$$

$$Y = Y_2 + 1000y_1 + \frac{x_2}{x_1 + x_2}(Y_1 - Y_2)$$

$$Y = Y_3 - 1000y_2 - \frac{x_1}{x_1 + x_2}(Y_3 - Y_4)$$

$$Y = Y_4 - 1000y_2 + \frac{x_2}{x_1 + x_2}(Y_3 - Y_4)$$

The four X and Y solutions shown above always agreed to within 3 to 30 feet of each other. An example of the calculation for the SPC's of a land use control point is exhibited as Figure 3.

The SPC's of all seven control points were thus calculated. Choosing one point near the center of the photo and another with approximately the same elevation near the edge,

the scale in this direction was determined by measuring the distance between the points in inches and dividing by the true ground distance obtained from the SPC coordinates calculated above. This scale was used as the "base" scale for the ensuing land use map. The land use map was then geographically "tied down" in the following manner.

Using the base scale and the SPC's of the control points, these points were plotted on a non-shrinkable, mylar base sheet. The air photo was placed under the mylar sheet and oriented until the two control points which were used to determine the scale coincided between the photo and mylar sheet. The other five photo and mylar control points will not generally coincide since the photo has a varying scale dependent on elevational changes. The photo control points were then marked on the mylar base. The distance and direction from the initially plotted control point (the map position) using the base scale and the imaged position (just marked on the mylar from the underlying photo) is the distance and direction which the mylar should be displaced when tracing the land use boundaries in this region of the photo. By thus partitioning the air photo into regions of fairly constant scale, reliable land use maps with positional accuracies not exceeding 80 feet were compiled of Woodland Hills. By this method, the Planning Department can perform the same type of map compilation for other areas limited in geographical extent and elevation variation without the expenditure of funds for a photomosaic.

The Woodland Hills land use maps were constructed in this manner – sliding the transparent tracing sheet over the air photos to adjust for relief displacement and tracing the polygon boundaries of different land uses utilizing the principles of air photo interpretation and classifying the interpreted land uses from the Delphi-selected land use data items described under "Delphi Land Use Needs Study." Sixteen polygons were ground truthed by car as they could not be positively identified from the air photos alone. The most difficult land use discriminations to interpret from the photos alone were the distinctions between large food stores and banks and between small day care centers and private church schools. Riding stables were also difficult to interpret from the photos alone as they are generally concealed by crown cover in the Woodland Hills region of the city.

The penciled land use mylar polygon maps for all of the Santa Monica Mountains were then inked on a second overlay. In the case of the pilot area maps in Woodland Hills, the mylar inked maps were photographically reproduced onto two matt finishes per map. One matt was used for polygon identification and digitizing. The second matt was colored according to seven broad land use categories. The colored land use maps of Woodland Hills for the years 1970, 1972, and 1974 are illustrated in figures 4 through 6, respectively. For the rest of the Santa Monicas outside of the pilot area interpreted by Cornell University, the one available inked land use map per area was digitized directly.

It is interesting to analyze the land use changes in Woodland Hills during the years 1970 to 1974 utilizing figures 4 through 6 as the Los Angeles City Planning Department is presently doing. Pierce College is the large dark island in the sea of dark farmland in the northeastern corner of the figures (pt. 3). The rapidly disappearing farmland signifies the foreseeable end of agriculture as a resource in the City of Los Angeles. Note the threat to agriculture and open space in the top central portion of the maps – the encroaching light shopping centers and banking institutions (SW of pt.2). The entire large dark graded area in this region, near Topanga Canyon Boulevard in 1972 (figure 5), has been completely built over in 1974 (figure 6). However, the multi-family units (white) are staying fairly constant except for some building in the central region near Topanga Canyon Boulevard. The activity encouraging shopping center developments is the large increase in single family residences, a trend quite dissimilar to other regions of the San Fernando Valley, where the ratio of condominium starts to single family housing starts is higher and continuing to grow (in 1975). The large increase in single family units is manifested by the dwindling dark open spaces in the southern, mountainous areas of Woodland Hills near the large, dark island (the Woodland Hills Country Club, pt. 6) in the sea of gray. Note that the large triangular dark graded area at the southern border of the pilot area in 1972 has been completely covered by single family residences in 1974. Also note the dark terracing at the south-eastern border of the area in 1974 revealing the probable direction of new single family housing construction in the near future.

The following section illustrates the computerized procedure whereby the qualitative analysis performed above can be numerically described in terms of acreage and acres of change per year to allow the Los Angeles City Planning Department to apply the information contained in maps such as figures 4 through 6 for land use policy decisions.

POLYGON INTERSECTION OVERLAY SYSTEM

The main objective of the LUMIS Task was to develop a system consistent with the Los Angeles City's line printer mapping capability of their IBM 370/165. However, during the summer of 1974 it became apparent that system incompatibility would be a problem. Batch processing for development of the system at JPL was to be done on a UNIVAC 1108. Thus, conversion software had to be established to insure the transferability of JPL developed LUMIS products to the City's computer operations.

The second and far more basic problem regarding computer system compatibility is the conceptual difference between ordinal and nominal data systems (ref. 4). Ordinal systems are "number referencing," i.e., data or information is referenced to a geographical system. Thus, natural resources such as forests, rivers, cropland, and geologic formations are mapped with selected identifiers (total area, boundary, centroid) referenced to a selected geographic coordinate system. Nominal systems are "name referencing," i.e., data or information is referenced to a name designating system. Number of elderly persons over 62 years of age, total land improvement value, and percent families with unmarried female heads of household are data items referenced to a name; e.g., a block, tract, or councilmanic district (ref. 5).

The distinction between these two types of systems appears obvious; yet very few remote sensing specialists and information systems developers seem to have grasped this distinction. This misunderstanding by the remote sensing profession is manifested by the desire to digitize all areal units and relate census and other similarly referenced data to ordinal data via coordinate overlays. This approach, while valid, ignores all the DIME file technology developed by the U.S. Census Bureau for the purpose of aggregating nominally referenced individual data items to polygons of census geography. The planner, similarly, aggregates line scanner pixels to a name unit in order to give the area of alluvial fan in a district. Both points of view reflect the lack of appreciation for the importance of various means of data referencing. The "Ordinal" man thinks of geographic coordinates and the "Nominal" man thinks of place names. The "Ordinal" man thinks that nominal data can be easily interpolated, extrapolated, or aggregated to some polygon other than the orginally referenced polygons. Although there are spatial population projection models, to employ them over geographic space destroys the concept of an information system, which should be designed from observation, not theory (ref. 6). The "Ordinal" man has yet to understand that "Nominal" man is interested in place names; socio-economic data such as people and land values move geographically too fast for "Ordinal" man – his geographic system is stagnant with respect to people.

If a Councilmanic District boundary moves 20 blocks westward in one year, the Councilman is more concerned with the change in the number and characteristics of his constituents than the precise geographic location at any instant of time. An argument can be made that he should be concerned, since the coordinates involved in precisely describing the boundary may have impact on information applicable to engineering activities in the area. This fundamental understanding between the engineering ordinal and the planner's nominal data systems has been of great benefit to the LUMIS staff.

The LUMIS approach to the ordinal-nominal systems incompatibilities is outlined in Figure 7. Basically, it involves the spatial definition of census areal units; i.e., the block, block group, and tract in terms of the California Zone 7 State Plane Coordinate System. These, in turn, are used as the map and land use geographic reference units. Flexibility is provided in the interactive graphics mode described in the next section by allowing both an ordinal presentation of the land use or physical resource as a polygon boundary and a nominal presentation of population and housing near the centroid of a name designator (tract 1340.01, block 302, of figure 7). The LUMIS computer subsystems have a provision for converting the ordinal polygon boundaries to nominal block acreages by means of polygon overlay software. Since LUMIS is a block level system, i.e., the census block is the smallest aggregate unit, the distinction between ordinal and nominal systems is made since there is no method by which the nominal socio-economic data can be geographically distributed within the block. The desire of

"Ordinal" man to force his system must be addressed by parcel level identifiers (ref. 7). Census blocks are irregularly shaped, hence geographical overlaying of land use and other map polygons over census blocks requires digitization of both census polygons and polygons drawn as overlays from maps and aerial photo sources. The use of census blocks as the land use geographic reference unit has the advantages of the utility of existing Metropolitan Map Series, the existence of digitized block nodes in many SMSA's[1] of the United States, and the topological chaining of digitized street segments into blocks, block groups, and tracts by means of the U. S. Census Bureau DIME (Dual Independent Map Encoding) file edit software. An additional advantage is gained in urban areas since census blocks are usually defined by street boundaries and are hence easily recognized on aerial photos (as opposed to artificially defined Universal Transverse Mercator or State Plane Coordinate grid cells). The street pattern and contained land uses are thus visually preserved even in the presence of photo tilt and relief displacement so that gross overlay errors from non-orthographically corrected photos are easily detectable.

The chief disadvantage of census blocks is the low accuracy of boundary location – usually the width of a secondary street (approximately 80 feet). Census block boundaries are generally defined no better than the width of a street and in some instances run along an arroyo or river where the boundaries are even more poorly defined. It should be remarked, however, that land use boundaries are generally no better defined by remote sensing or any other means since, for example, the precise line between family residential areas and wooded lots is difficult to perceive and define. Unless very precise definitions for land use boundary designators are set (which is generally not the case), in remote sensing the definition is the sharp discontinuity between spectral signatures or interpreted patterns and tones, which may be completely unrelated to land use. It is suggested that the definitional clarity of census block and land use polygon boundaries are quite compatible.

The census blocks become the major polygons in the overlay technique employed in LUMIS. Eight other digitized map type polygons, or map models, become the minor polygons. Major polygons are census blocks which, after processing with the polygon overlay software, contain the information overlaid from the minor polygon. These minor polygons are created from land use and natural resource maps (which in turn are created from air photo processing), slope maps (in turn created from elevation maps), elevation maps, geology maps, landslide and fault maps, soil maps, and air pollution indices.

The polygon overlay software is the PIOS (Polygon Intersection Overlay System). PIOS was originally developed for the San Diego Comprehensive Planning Organization (CPO)[2] by Environmental Systems Research Institute (ESRI) of Redlands, California (ref. 8). The system was designed and implemented in 1971 under a contract from CPO to ESRI to digitize soils polygons of San Diego County and then quantify soils type within Traffic Analysis Zones (TAZ), statistical areas used for planning purposes by CPO. PIOS numerically overlays any general set of geographically referenced polygons, two members of the set at a time, and produces a residual polygon of the intersecting polygons' common boundary and the area of intersection. This residual polygon can be overlaid with a third polygon, and so forth, each overlay producing a residual polygon of common intersection. This overlay system is conceptually similar to a "cookie cutter".

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[1] Standard Metropolitan Statistical Area. The advantage of digitized block nodes is questionable. LUMIS staff found serious errors in ten percent of several hundred previously digitized nodes in the Santa Monica Mountains. We therefore discarded this file and redigitized all these block nodes for our own use.

[2] The LUMIS staff acknowledges Mr. Lee P. Johnston and Terry de Berry of the CPO for their help in acquiring PIOS.

Overlay processing is the most severe demand imposed upon any polygon information system. It requires massive computation of polygon records while searching the files. The overlay capability of PIOS includes several features that minimize this computer processing (ref. 9):

1. Each polygon record carries extremity coordinates that define the extreme X and Y coordinates for that polygon. This eliminates a great deal of initial file scanning.

2. All polygons are complete and not related to a map window. This means that polygons appearing on separate maps are connected along the borders. This has the effect of removing all of the source map borders and irrelevant boundaries.

3. A unique quadrature procedure for strip analysis of polygons is employed which has proven to be faster than the conventional point-in-polygon methods.

The PIOS software has been modified at the Jet Propulsion Laboratory to provide a data file of acres of land use and other map variables referenced to the individual census block. The final overlay analysis uses this file and converts it temporarily into a work file usable by the polygon overlay program. This work file is composed of an arbitrary map windowing system. The windowing technique allows for various rectangular areas to be sorted out of the data file permitting computational analysis or graphics display of any given area. The rectangular area resembles, in many ways, the border of a map. It essentially is a technique for selecting a designated area from a continuous geographic data file. In this way any geographic area can be windowed and pulled off the file for subsequent analysis according to the coordinate rectangle specified. It should be noted that the original map information was digitized from a rigid map windowing system being composed of land use maps, MMS maps, geology maps, and others.

Having windowed the final master file into a temporary work file, the polygon overlay program accesses this work file for the purpose of aggregating and summarizing the areas (by average) of the subordinate polygons by homogeneous types (land use, geology, others) into each dominant polygon type (census block).

Considerable analysis has been done on various techniques for the polygon overlay analysis (ref. 9). The most basic of these techniques involves the point-in-polygon technique. Using a polygon data base, this type of algorithm calculates the location of single points relative to polygons. A point may lie inside, outside, or on the line of a given polygon. Because polygons are defined by chains of points surrounding each polygon it is a simple step to organize the point-in-polygon technique so that it can do polygon overlay analysis.

A second method involves the generation of a grid cell technique with a variable grid cell size for varying sizes of polygons. If a correct amount of computer storage is allocated, this technique allows the user to specify varying degrees of inaccuracy and a grid cell size can be selected for each dominant polygon. Each dominant polygon and the associated polygons that are overlayed are assigned a cell size dependent on total polygon size and its perimeter length. If the polygon is made up of a 0.01 inch grid then the accuracy is at the same level as the thickness of the lines on the input maps. However, land use polygons can be quite large (i.e., 100 square inches) and a perimeter description can involve as many as 2,000 vertex points. For this size of polygon to fit into a reasonable core space, it would be necessary to choose a cell size an order of magnitude larger than 0.01 inch. This large grid size introduces unacceptable inaccuracies.

The San Diego CPO grid cell program that was written, however, is substantially faster than the point in polygon routines and if the polygon sizes are reasonably small (2 - 3 square inches) the algorithm is quite useful (ref. 9).

The third technique investigated proved quite successful and is used in PIOS. It involves a hybrid of the standard point-in-polygon routine. This technique is an efficient polygon stripping technique that subdivides data for subsequent point-in-polygon calculations.

The general logic of this stripping technique is not unique, but it does provide for a substantial increase in efficiency. Briefly the technique involves reading in a major polygon and partitioning it into a predetermined number of strips. The number of strips is determined by the tradeoff between efficiency gained in the processing and the core storage requirements necessary to run the program. It should be noted that as the complexity of polygons increase the efficiency gained by increasing the number of strips also increases. The coordinates of the polygon are stored in an array such that it is possible to maintain points to each set of side points that make up each strip. New points are generated at strip boundaries so that each strip is wholly contained.

Since the point-in-polygon technique uses directed line segments in the positive x-direction of slope zero, each point of interest will appear in one, and only one, strip and the directed line segment will not cross over onto another strip. Therefore, to determine if a point is in or out of the polygon, only a single strip and not the entire polygon needs to be considered. This amounts to considerable reduced machine costs (see figure 8).

After the major polygon (census block) has been stripped a minor polygon (land use, for example) is read in to compute the intersection points, if any. Each point in the minor polygon is tested for being in or out of the major polygon. This information is kept in a memory table. After the special case of locating the first point has been considered, four possible actions are taken by the program when considering the remaining points. They are as follows:

Please refer to figure 8. Let the subscript 1 indicate the first (or previous) point and 2 the next point of the same polygon. Let I indicate a minor polygon point inside the major polygon and O a minor polygon point outside the major polygon. Let B_i be a set of arbitrary points on the major polygon boundary with, in this example, B_1 and B_3 being major-minor polygon boundary intersections.[3] The four possible conditions and the actions taken are tabulated below:

First Minor Point Condition	Example	Second Minor Point Condition	Example	Action Taken
IN	I_1	IN	I_2	Add point to the line segment defining the new polygon being calculated.
IN	I_1	OUT	O_2	Find intersection (B_1). Determine direction on major polygon. Follow major polygon until it goes out of minor polygon (B_1 - B_2 - B_3).
OUT	O_1	IN	I_2	Find intersection (B_3). Determine direction on major polygon. Follow major polygon until it goes out of minor polygon (B_3 - B_2 - B_1).
OUT	O_1	OUT	O_2	Throw away point O_1. Do not consider segment as part of polygon.

[3] B_1 and B_3 are actually calculated by PIOS since the equations of the straight line segments joining adjacent points on both major and minor polygons are formed from the digitized coordinates of these points.

After selecting one of these actions, a new polygon is developed and subsequently computed for area.

Having sorted all of the acreages of each minor polygon type by census blocks, this preliminary listing of polygon sizes is summarized into a final file containing the integration of map types within specified census blocks.

INTERACTIVE GRAPHICS TERMINAL

In addition to the polygon overlay software, a secondary objective of the LUMIS task was to demonstrate the potential of interactive computer graphics to the City to illustrate the value of an advanced LUMIS operating system. An interactive system with computer graphics capability was initiated on a short term lease with two vendors — one supplying the terminal and the other supplying APL software support.[4] This lease was decided upon since the City, should it choose to support a similar graphics system, would most probably follow a similar mode of terminal support initially. The lease period for the terminal in the LUMIS Task expired at the end of December, 1974. A successful demonstration was given to the Planning Department staff prior to its expiration. That demonstration has resulted in the Planning Department considering the establishment of a similar system.

In the meantime JPL has established the APL language on the Caltech PDP-10. Since JPL has many computer terminals, further interactive terminal development will now be performed on the PDP-10. There was thus a definite need to make all LUMIS software easily transferable, an original objective of the task, since the polygon overlay system was developed at JPL on a UNIVAC 1108 and was transferred to the City IBM 370, and the interactive system was transferred from a local vendor to the PDP-10 and finally will be transferred back to the local vendor's computer or the City's IBM 370.

The interactive graphics system basically takes the same input as PIOS; i.e., digitized block boundaries and map polygons. Whereas PIOS overlays various digitized polygons and creates a residual polygon of common intersection to relate map information to an individual census block, the graphics routines display the digitized polygons (the ordinal data) in map form and the socio-economic data (the nominal data) at the polygon centroids. (Refer to figure 7.) To date (June 1975) the interactive graphics system encompasses strictly one hundred and seventy-three socio-economic data items regarding population, housing, and land use for six census tracts (approximately two hundred blocks) in Woodland Hills, California. The socio-economic data items were obtained by merging the Third Count U.S. Census tapes and the Los Angeles County Secured Assessor File for these six tracts. A similar merged file for the remaining seventy-eight tracts in the Santa Monica Mountains has been supplied to JPL by the Los Angeles Planning Department. This data has not yet been inputted to the interactive software, nor has additional development of this system been performed as the City has not yet committed itself to supporting terminal development.

The six digitized tracts contained in the interactive system are located in the western tip of the pilot area (please see figures 4 through 6), west of the line formed by extending Shoup Avenue south to the Los Angeles City Limits. The six tracts consist of three north of the Ventura Freeway (1351.01, 1372.01, and 1372.02) and three south of the Freeway (1374.02, 1374.01, and 1375.02). The three tracts north of the freeway are representative of some of the more congested residential and commercial areas of the City of Los Angeles and the three tracts south of the freeway are some of the most rapidly changing tracts in the city from the standpoint of transition from open space to single family units. The transition has been aptly discussed under the subsection "Air Photo Interpretation".

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[4] Tektronix, Inc., and Proprietary Computer Systems, Inc., respectively.

Figures 9 through 11 are polaroid shots taken of the interactive terminal with a demonstration set of census blocks displayed. Since the basic units are digitized census blocks, they represent true-to-scale street maps of two different block groups in Woodland Hills. Since they also reveal block aggregates of algebraically-combined socio-economic data, these figures illustrate an interesting merger of an ordinal and nominal data system. The variables are significant in themselves.

Figure 9 reveals the percentages by block of persons 62 years of age or older to the total population of that block. The block group shown is 300 in census tract 1375.02. The relatively lower percents of elderly in the more expensive, winding blocks in the center and east side of the tract conform to the common image of the San Fernando Valley's youthful population. Note that in many blocks City data has been censored to LUMIS staff. The user-provided algebraic expression to access this data and combine it into a planning variable is illustrated at the top of the terminal.

Figure 10 is an interesting example of how temporal trends can be detected using combinations of data. Although land use data from remote sensing imagery has not yet been added to the system, the land use maps prepared from this imagery were available. Using this map and previous displays of single family and multi-family units, LUMIS staff knew that this block group (100) of census tract 1375.02 is composed strictly of single family units except at the north along the Ventura freeway. Since the Assessor File contains 1974 data and the Housing Census contains 1970 data, a look at the change in single family units can be obtained by selecting the right variables from each file. In the user-supplied expression at the top of the terminal, SFD is the single family units from the 1974 Assessor File and OCC + VACANT is the sum of the 1970 total occupied units and vacant units for sale. Note the increase of 27 and 29 housing units in the southerly mountains of this block group. The 1970, 1972, and 1974 aerial photography reveals the clearing and terracing associated with preconstruction of these homes, as pointed out in the subsection "Air Photo Interpretation".

Figure 11 is the same block group as Figure 10, indicating the total improvement value for each block divided by the number of parcels on which improvement took place in 1974. The ratio is a measure of the average improvement value per lot. Note the high two and one-half million dollar improvement (a commercial development) near the freeway. Also note that the block with censored data in Figure 11 is one of the same blocks censored in Figure 10.

The LUMIS interactive graphics package encompasses a user oriented, English language mode for communication with the APL routines necessary to graphically display the ordinal data and to call the PL/1 programs which manage and access the data files.

CONCLUSIONS

Delphi study. - The Delphi Study was a tremendous benefit to LUMIS staff in reducing the number of land use data items from 164 to approximately 74. It eliminated the need to acquire land use information concerning manufacturing, trade, and services which would have necessitated data sources other than aerial photography and City files. By eliminating most subcategories of climate and all of physiography, wild life, and aesthetics, items which were difficult to define - let alone interpret - were avoided. Vegetation is retained in the inventory since this land use is critical in zoning and fire insurance. The remainder of the retained items are relevant to planning in the Santa Monicas and are fairly easily interpretable from aerial photography.

The Delphi study was probably more important in the personal interaction the study provided between LUMIS staff and the leading land use planners in agencies throughout the Los Angeles basin. These relationships have permitted LUMIS staff to become involved in other land use planning activities unrelated to the Santa Monica Mountains, thus providing future potential applications for LUMIS.

Interactive computer graphics terminal. - The LUMIS system (utilizing PIOS) has been set up on the City's computer and allows the data to be used by the City Planning Department in its normal mode of operation. Implementation of the interactive graphics system would allow a more efficient mode of operation to be developed. Many planning examples similar to figures 9 through 11 were demonstrated to the Los Angeles Planning Director and staff. It was pointed out that to have at hand 173 data items for the approximate 200 blocks on line in the terminal would require several volumes of computer printout. To have at hand data for the entire Santa Monica Mountains would require a library of computer listings in table form. The LUMIS terminal provides a scaled street map and links the City's data to it almost instantaneously. The current software encompasses English language user statements and a self-instructing mode to assist the user in displaying tables and maps of selected areas. In summary, the Director of Planning has agreed that the interactive terminal development of the LUMIS task could be a vital tool in planning and zoning in the Santa Monica Mountains, and a proposal has been initiated for the City to support interactive terminals.

The method of digitizing census units in the LUMIS project has been done on a street segment basis to facilitate block, group, and tract chaining. This method is compatible with U. S. Census Bureau DIME-file editing and was done to allow rapid retrieval of any census areal unit in the hierarchy of units. Thus, the LUMIS methodology has direct transferability to all urban agencies building files and information systems based on DIME files. For areas which do not have accurately digitized block nodes, the LUMIS scheme of digitization is certainly appropriate.

The interactive terminal development to date satisfies Los Angeles City planners in their need to spatially relate urban variables. This satisfaction is due to the capability of the system to overlay dynamic socio-economic variables at an instant of time and geographic blocks into which the variables were originally aggregated. This is a first step toward more effective land use management through integration of differently referenced information – ordinal, and nominal. The LUMIS staff clearly recognizes that much further work needs to be done in this integration research of different data referencing systems.

Integrated approach. - As well as the integration of information systems and data referencing units, the LUMIS staff recognized that the integration of various disciplines and institutions would be necessary to effectively implement a land use information system. Much of the information system developmental research was performed by JPL engineers at City Hall, whereas City planners were involved in LUMIS systems concepts from the start of the project. The Natural Resources Laboratory at Cornell University, with a staff of twenty-seven photo interpreters and resource managers, was retained for the important evaluation and processing of aerial photography. The very important Advisory Committees provided the direction and guidance to the LUMIS staff to insure that the project was truly a multifaceted solution to a real land needs problem, not an academic exercise to create a land use gaming tool.

ACKNOWLEDGMENTS

The LUMIS staff would like to take the opportunity to thank the many people who have helped to make this project a meaningful entry of remote sensing and interactive information systems into city government. The LUMIS Advisory Committees have been very helpful in maintaining a realistic approach to a very serious land use problem in the Santa Monica Mountains. Particularly, the time spent in discussing land use problems in Los Angeles by Mr. Jene McKnight of the Los Angeles Regional Planning Commission and Mr. Thomas Sisson of the City Administrative Office is acknowledged. The continuing interest and support of Mr. Calvin Hamilton, the Director of the Los Angeles Planning Department, has created growing awareness and interest at City Hall for the LUMIS project. We are deeply indebted to Mr. Lee Johnston and Terry de Berry of the San Diego Comprehensive Planning Organization for supplying us with the basic PIOS software. Finally, to the many planners, environmentalists, conservationists, politicians, and social activists we have passed in Planning Commission hearings, our thanks for reminding us that land use analysis is a study of people and why they come and go.

REFERENCES

1. Landini, A. J., and Paul, C. K., Results of Phase One of Land Use Information Delphi Study, California Institute of Technology, Jet Propulsion Laboratory, Special Publication SP 43-22, May 1, 1975.

2. Huckfeldt, V. E., and Judd, R. C., "Issues in Large Scale Delphi Studies," Technological Forecasting and Change; 6, 1974, pp. 75-83.

3. Allen, W., Sledge, B., Paul, C. K., and Landini, A. J., The Availability of Local Aerial Photography in Southern California, California Institute of Technology, Jet Propulsion Laboratory, Special Publication SP 43-14, Dec. 1, 1974.

4. Dueker, K. J., "Urban Geocoding," Annals of the Association of American Geographers, Vol. 64, No. 2, June, 1974, pp. 310-317.

5. Landini, A. J. "Description and Use of a Proposed Geographically Based Environmental Data Base System, Los Angeles City Planning Department, May, 1974.

6. Clawson, M., and Stewart, C. L., Land Use Information, John Hopkins Press, Baltimore, Md., 1965, pp. 114-118.

7. Moyer, D. D., and Fisher, K. P., Land Parcel Identifiers for Information Systems, American Bar Foundation, 1973.

8. Comprehensive Planning Organization of the San Diego Region, PIOS - II, General System Description, July, 1974.

9. Comprehensive Planning Organization, Polygon Information Overlay System, Sept. 15, 1971.

TABLE 1. RESULTS OF DELPHI SANTA MONICA MOUNTAINS LAND USE NEEDS

Evaluation	Land Use/Resource							
No. of Persons Voting	Residential	Manufacturing	Transportation, Utilities	Trade	Services	Cultural, Recreation	Agriculture, Mining	Underdeveloped
Very Important	8	3	9	6	4	9	7	9
Important	3	8	2	4	6	2	3	1
Not Important	0	0	0	1	1	0	1	1
Total No. of Persons Voting	11	11	11	11	11	11	11	11

TABLE 1. RESULTS OF DELPHI SANTA MONICA MOUNTAINS LAND USE NEEDS (contd)

Evaluation	Land Use/Resource									
No. of Persons Voting	Public Facilities	Climate	Geology	Physiography	Hydrology	Pedology	Vegetation	Wild Life	Aesthetics	Special Districts
Very Important	8	8	8	7	8	8	7	5	7	8
Important	2	1	1	2	1	1	2	3	1	1
Not Important	1	1	1	1	1	1	1	2	2	1
Total No. of Persons Voting	11	10	10	10	10	10	10	10	10	10

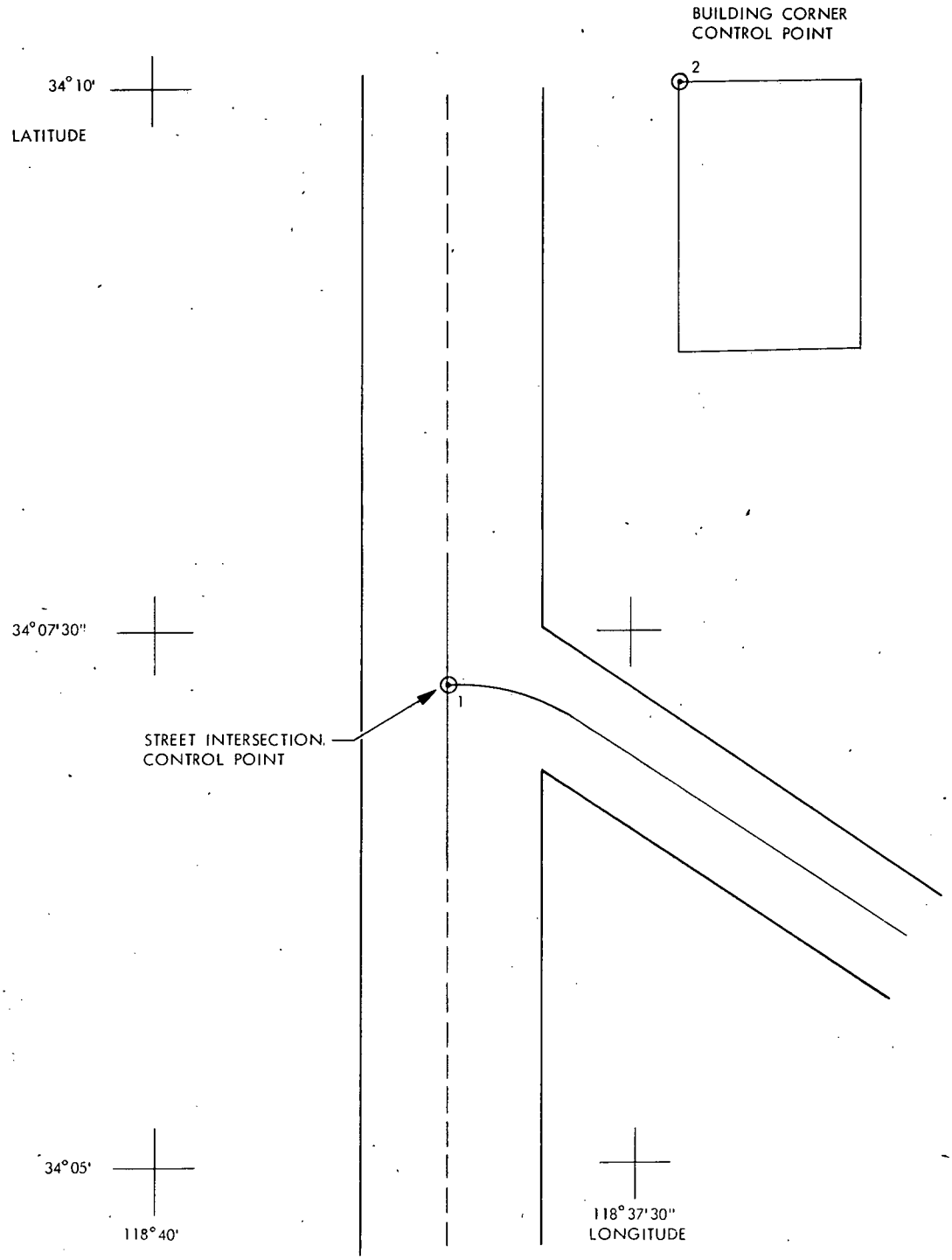


Figure 1. Geographic Position Determination of Control Points

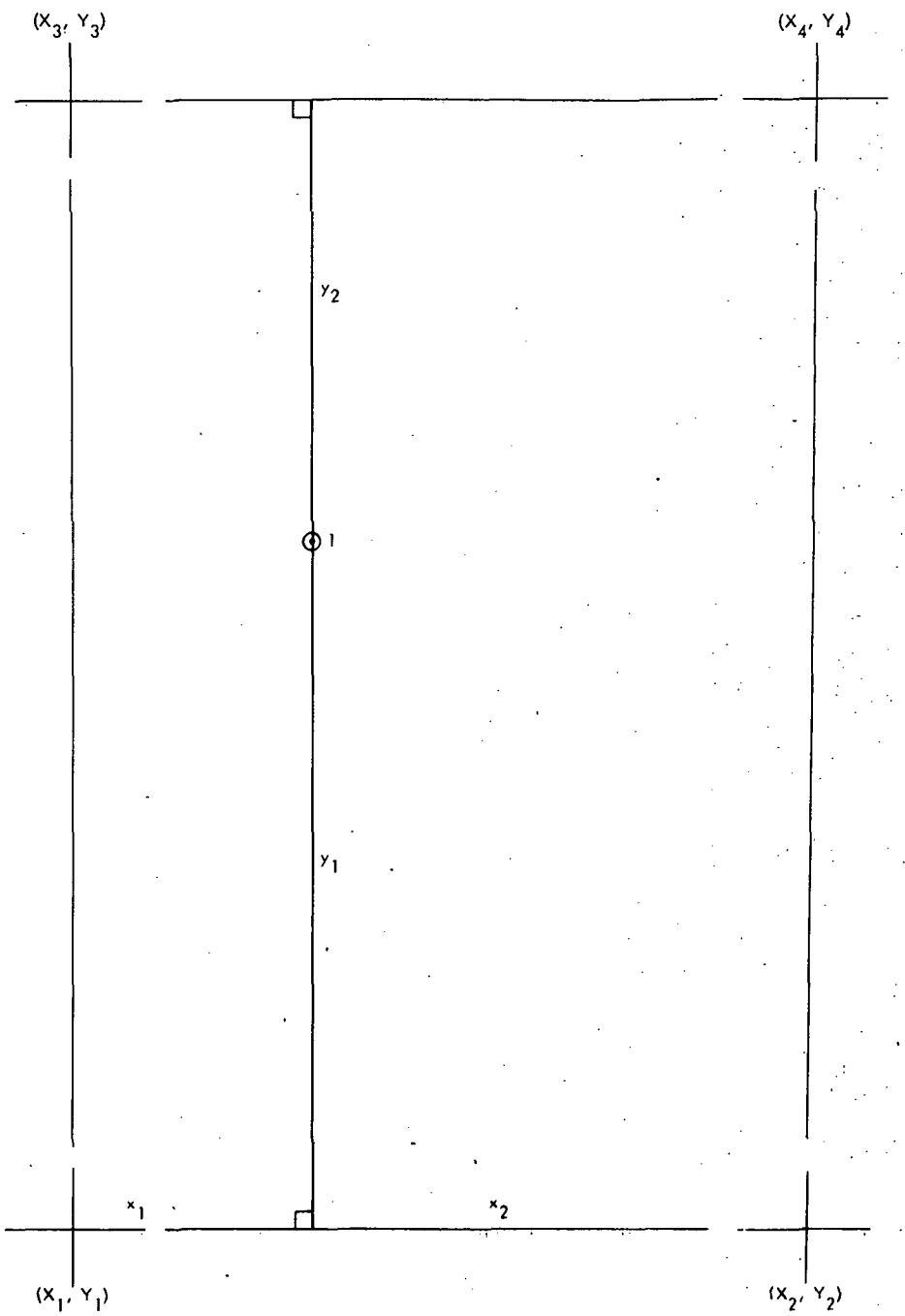


Figure 2. Geographic Position Determination of Control Point 1

LUMIS PROJECT TEST SITE

WOODLAND HILLS

LAND USE MAP 17001

REFERENCE POINT 1: INTERSECTION OF MULHOLLAND DRIVE AND NORTHBOUND FEEDER OFF VENTURA FREEWAY

ELEVATION: 900 FEET

	GRID TICS			
	SW 1	SE 2	NW 3	NE 4
LATITUDE	34° 07' 30"	34° 07' 30"	34° 10'	34° 10'
LONGITUDE	118° 40'	118° 37' 30"	118° 40'	118° 37' 30"
X	4085806.8	4098417.5	4085856.4	4098460.8
Y	4158058.9	4158020.2	4173221.8	4173183.2

$x_1 = 8.91$ $\quad X_3 - X_1 = 49$ $\quad Y_1 - Y_2 = 39$

$x_2 = 3.68$ $\quad X_4 - X_2 = 43$ $\quad Y_3 - Y_4 = 39$

$y_1 = 13.22$ $\quad y_2/\Sigma y = 0.8732$ $\quad x_1/\Sigma x = 0.7077$

$y_2 = 1.92$ $\quad y_2/\Sigma y = 0.1268$ $\quad x_2/\Sigma x = 0.2923$

	X	Y
	4094760	4171251
	4094760	4171251
	4094776	4171274
	4094776	4171274
AVERAGE:	4094768	4171262

Figure 3. SPC Calculation for Land Use Control Point



Figure 4. 1970 Woodland Hills Land Use Map



Figure 5. 1972 Woodland Hills Land Use Map

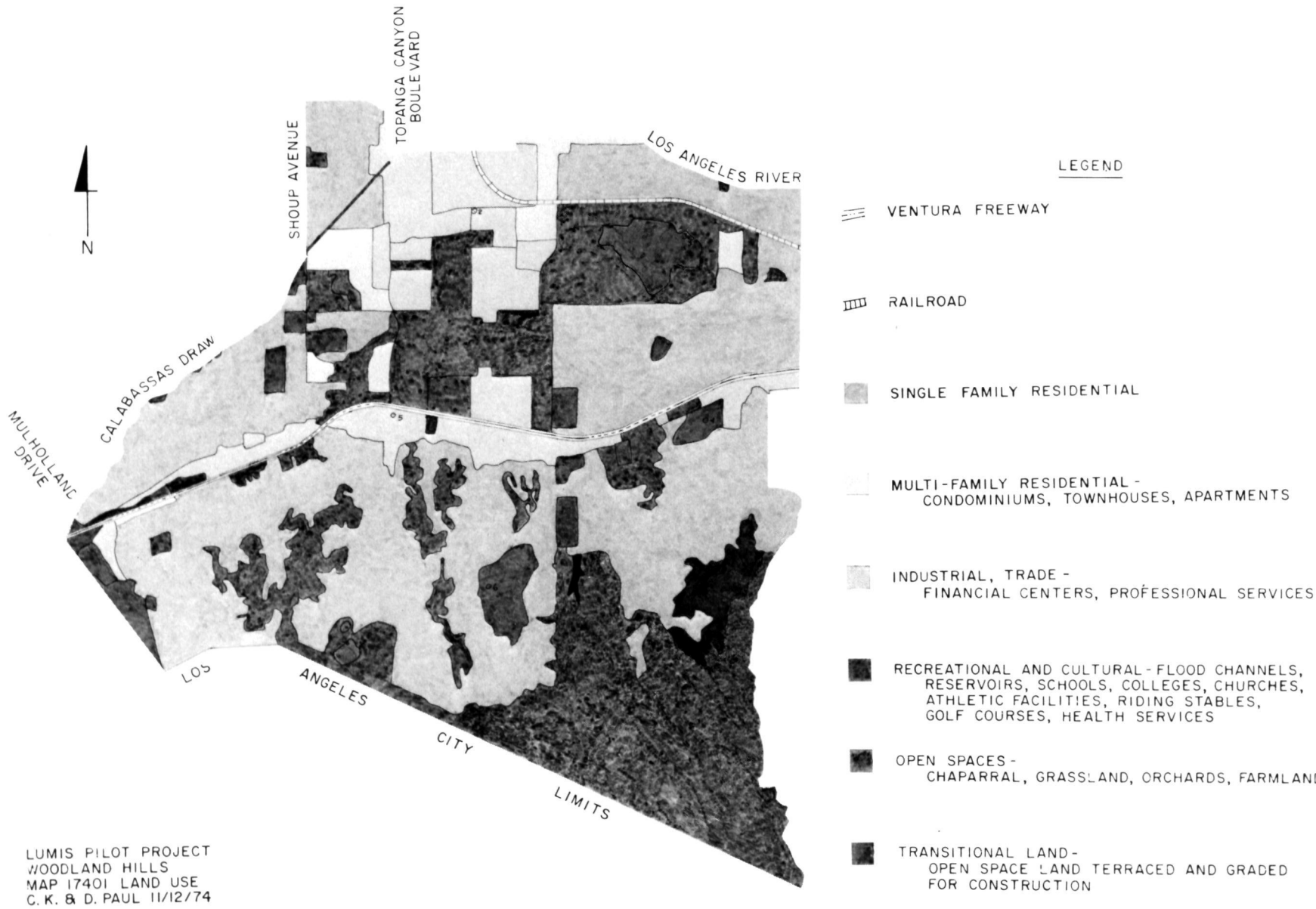


Figure 6. 1974 Woodland Hills Land Use Map

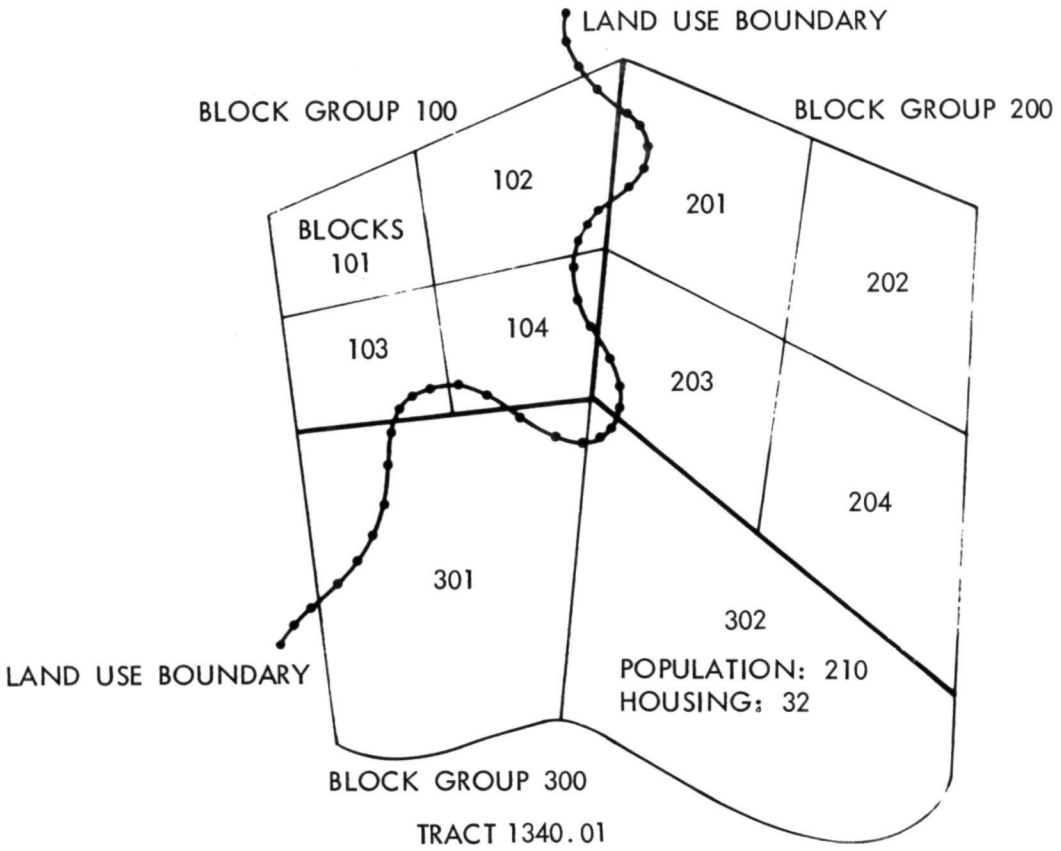


Figure 7. Ordinal-Nominal Systems Integration

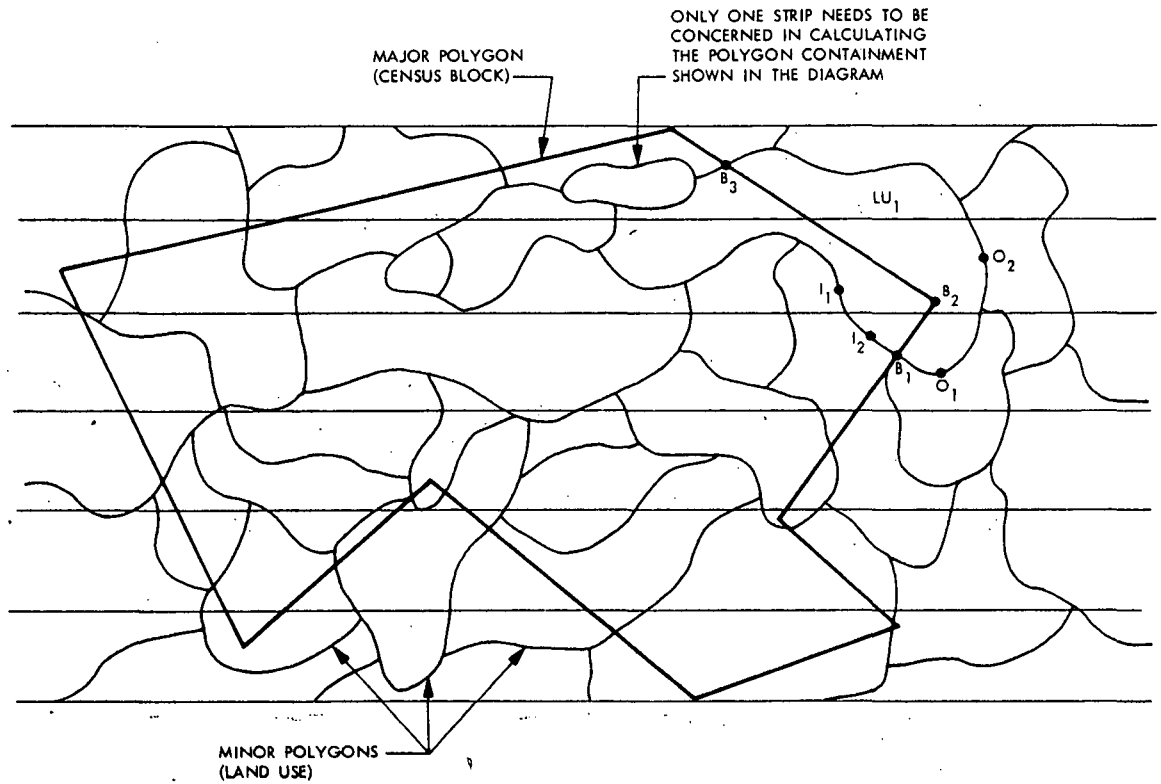


Figure 8. PIOS Stripping Method

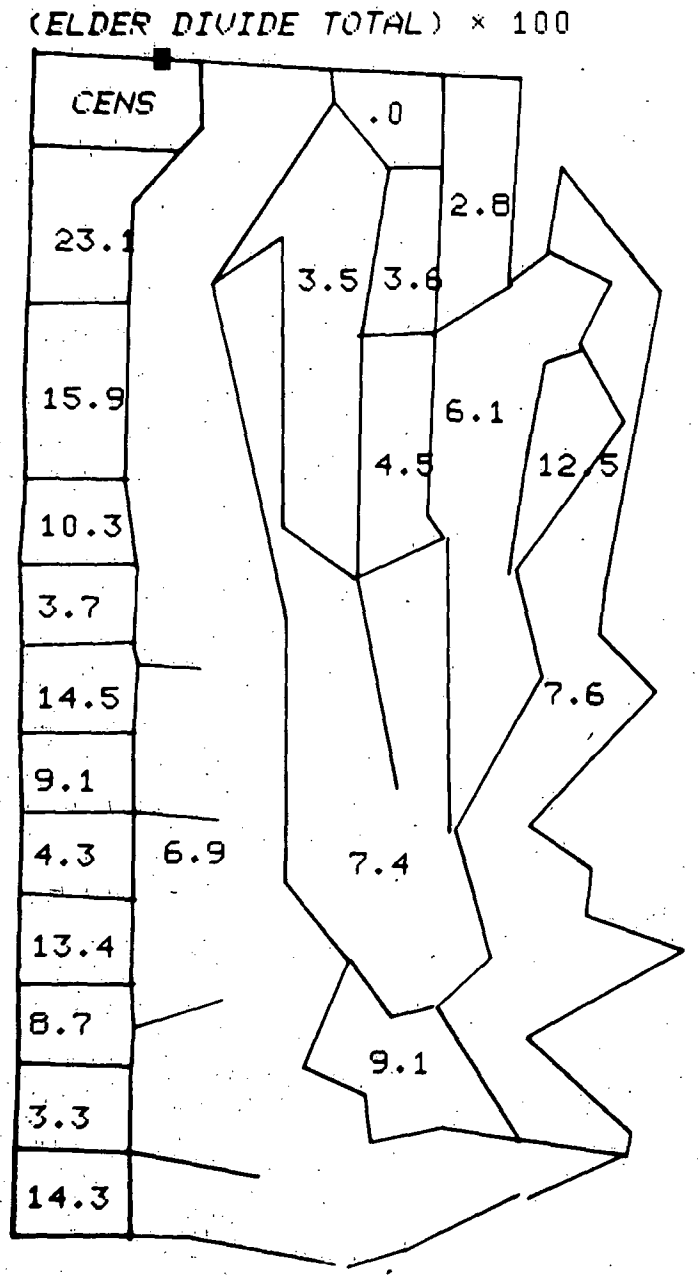


Figure 9. Percent Population Over Sixty-two in Age Block Group 300, Census Tract 1375.02 Los Angeles - Long Beach SMSA

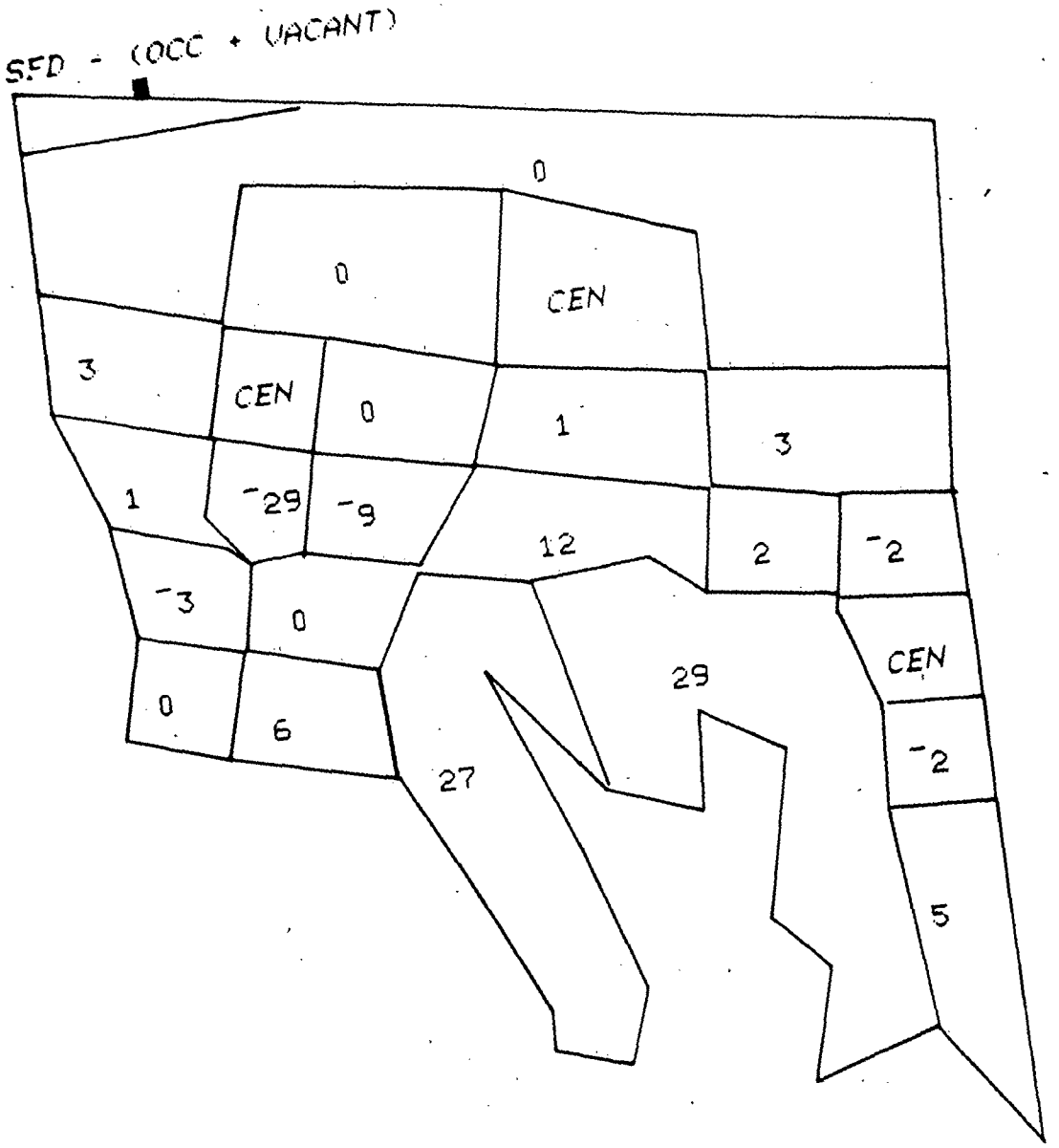


Figure 10. 1970-1974 Change in Single Family Dwelling Units Block Group 100, Census Tract 1375.02 Los Angeles - Long Beach SMSA

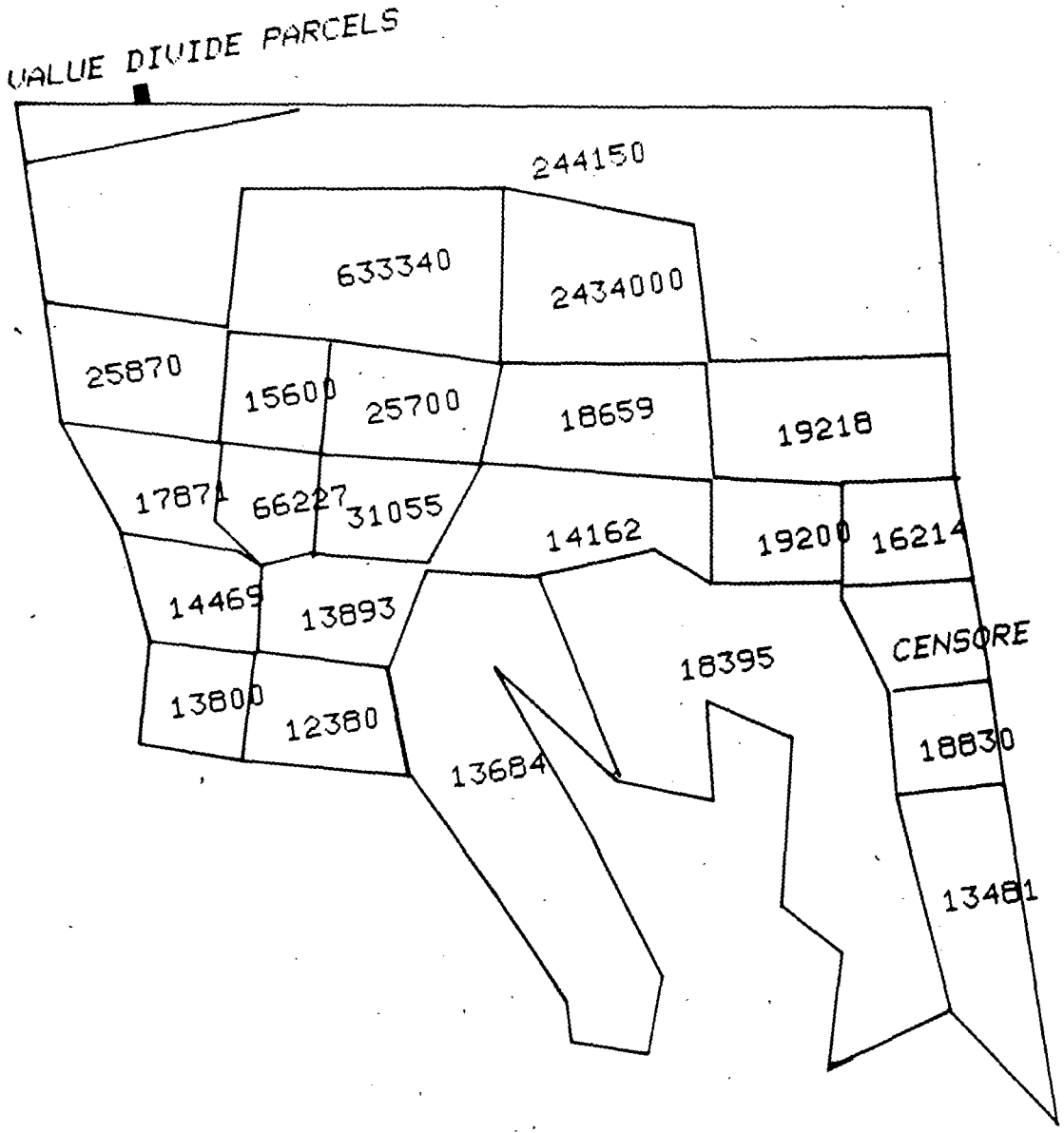


Figure 11. Average 1974 Improvement Value Block Group 100, Census Tract 1375.02 Los Angeles - Long Beach SMSA

SATELLITE INFORMATION ON ORLANDO, FLORIDA

L-13

By John W. Hannah and Garland L. Thomas, Brevard County, Florida, Planning Department and
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ABSTRACT

An effective means of coordinating the utilization of Skylab and LANDSAT data is use of the Skylab photography to make generalized land use maps of the larger areas, such as counties and regions, followed by use of multi-spectral scanner data from LANDSAT and Skylab, where available, to provide more detailed information for whatever portion of that area may be needed. This approach has been followed for Orange County, Florida, in which case EREP photography was used to prepare a land use map of the county and LANDSAT and EREP MSS data have been used to provide more detailed information on Orlando and its suburbs.

The generalized maps were prepared by tracing the patterns on an overlay, using an enlarging viewer. Digital analysis of the multi-spectral scanner data has been basically the maximum likelihood classification method with training sample input and computer printer mapping of the results.

Local planners have participated: the training samples have been selected by Orange County planners and Orlando City planners, and results have been checked in collaboration with them, using photography and their local knowledge.

Eight classes have been mapped. Tallies are kept of the number of resolution elements assigned to each class. Major streets and highways are drawn in manually by tracing on a light table from a master street map made from information combined from several types of computer-printed maps:

(1) the above classification map;

(2) maps of ratios of two bands; and

(3) maps of density - sliced data for single bands.

Thematic maps, consisting of one of the classes, or a combination of them, with everything else left blank, have been found to be useful and informative. Tracing to produce a basic land use map (omitting some of the real-life clutter) has been found to be easier from the separate class maps than from the composite map. The thematic maps are useful also in providing general information, such as industrial/commercial development patterns, to planners.

It was found that two types of residential areas could be discriminated: (1) the newer sections with higher density and relatively few large trees and (2) an older section with lower density and numerous large trees, designated as wooded residential. The pattern made by those two residential classes is visible on the composite map and is made more evident by a thematic map showing only those two classes. The wooded residential dominates in a fairly compact zone near the center of the city and extending into two relatively affluent suburban towns. The newer, or non-wooded residential can be seen to form a rough ring outside this inner area.

It is interesting to make a thematic map showing lakes, forested areas, and wooded areas; three features which increase the desirability of a residential neighborhood. Again, concentration in the more affluent sectors can be seen.

The maps also point out the not uncommon problem of intensive development outside the jurisdiction of the city responsible for that development. In this case, the subject area of intensive development is not only outside the city but also outside the county.

Change mapping is accomplished by mapping the subject classes, usually industrial/commercial, for different dates, then manually tracing a map to show the changes.

Most of the digital work has been done with LANDSAT data. Skylab MSS data were obtained for a pass over Orlando, but clouds limited the useful coverage to about a third of the metropolitan area.

A land use map of Orange County based on digital classification of LANDSAT data is partially completed. The procedure being followed is to prepare a basic map, to the detail permitted by the data, using the Anderson, Hardy, and Roach numerical designation system, from which the planners can then trace maps of whatever geometric and classification detail they choose. Training samples are selected by the Orange County planners and checking of results is done in collaboration with them.

INTRODUCTION

The Brevard County, Florida, Planning Department, in collaboration with Kennedy Space Center, is engaged in a study to evaluate applications of satellite data to local and regional planning in East Central Florida. Computer programming and use of computer facilities and data analysis facilities of the Earth Resources Branch have been provided by Kennedy Space Center. The methods used are conventional; the distinguishing features of this investigation are the application to specific problems at the local level and the participation by local planners.

It frequently is stated that the principal planning applications of satellite data will be on regional problems. This is perhaps true; but the authors and others have found that there also are useful applications of interest to county and city planners.

Both LANDSAT and EREP data have been used in this investigation. An attempt has been made to correlate the photography and multi-spectral scanner data from the two satellites and find the most appropriate use of each type of data.

As Orlando is the largest city in this region, this report will describe results related to it and its county, Orange. These are early results, subject to further checking, but they illustrate directions for fruitful study.

METHODS

Clouds limited the usefulness of EREP multi-spectral scanner, data for Orlando; so this discussion, for EREP data, will be limited to photography. Land use maps have been made from this photography by enlarging it in a Variscan viewer and tracing the patterns on an overlay placed on the viewing screen. In the case of S190A photography, which was used to make the map described in this report, each of the six films can be used, in turn, with

the overlay to bring out the features most readily seen on each film. Usually one of the infrared bands is used first, to locate the lakes (of which there are many in this area) as reference locations. The color infrared film usually is used next because of the wealth of information which it provides, followed by the color film (particularly useful for urban information), and then the remaining three films.

Land use patterns are mostly well defined; the problems lie mainly in the interpretation of the land uses associated with the various sectors of the pattern.

S190B photography can be used separately to make a land use map, or the further detail which it provides can be used to refine the map made from S190A photography, as was the case for the map described in this report.

Computer classification is used for the LANDSAT multi-spectral scanner data. Our usual procedure is to make a preliminary map from the ratio of the intensities of two bands (usually band 7/band 5) and use it for locating training samples. Training sample selection is usually done by the city or county planners directly concerned, using photography and their local knowledge. This serves the two purposes of providing reliable training samples and initiating indoctrination of those planners in the use of satellite data. The maximum likelihood method (sometimes preceded by a preliminary classification based on shortest distance) is then used to classify the data. Output is in the form of a computer printer map accompanied by a tabulation of characters.

RESULTS

County Land Use Mapping

Generalized - The Orange County Planning Department is interested in preparing up-to-date land use maps, and we believe that mapping of the satellite data will be an important part of this process. As a first step, a generalized land use map of the county has been prepared from EREP photography by the method described above. Nine inch EREP enlarged transparencies were enlarged further on the Variscan by a factor of approximately 6, giving a final product with a scale of approximately 1/126,000, a reduced version of which is shown as Figure 1. More detail could have been drawn on this map but was omitted for clarity. Later experimentation with a similar map for another county indicates that more information can be presented satisfactorily if the Variscan enlargement, and the resulting scale of the map, are increased by a factor of two.

The procedure in the case of this map was to prepare it in the manner described above, give it to the Orange County Planners to check for accuracy, then modify it in accordance with their findings. In this case, the modifications were minor.

A map of this type is of limited, general use to a county; but a set of such maps of the individual counties comprising a region is quite useful to regional planners, according to those regional planners with whom we have discussed such maps.

Detailed - A map such as Figure 1, in addition to its direct utility, is also useful in providing correlation and guidance in the next stage of land use mapping: preparation of a detailed land use map. An effective way of doing this is computer classification of multi-spectral scanner data, either EREP or LANDSAT. Since the latter type is more generally available,

it will be used more often, as has been the case for Orange County.

Training samples were selected by Orange County planners, a maximum likelihood classification performed, and a computer printer map produced.

Some planners have difficulty relating to a computer printer map, and most of them find it less "readable" than they would prefer. Hence, at this early stage of development of use of satellite data, at least, it seems desirable to present the results in a simplified form. In our case, this currently is done by tracing the computer character pattern on an overlay, simplifying the map in the process to reduce some of the clutter. Most of the clutter is real (Real-life land use certainly is cluttered.), but land use maps traditionally simplify.

The result of this process for a portion of the western part of Orange County is shown as Figure 2.

While we have referred to this map as detailed, it is possible to include more detail, both geometric and in terms of further division of land use classes, if desired. Within the limits of the capability of the system, the amount of detail presented depends upon the use to be made of the map.

As before, the first version of the map is given to the Orange County planners for their modifications prior to preparation of the final version.

As will be noted, this sector of the county is dominated by citrus groves. Such groves present the most severe classification problems we have encountered to date for two reasons: (1) the spectral characteristics of citrus groves vary widely, and (2) much of the non-urban area with which we are concerned is devoted to citrus. The wide spectral variation apparently is due primarily to the varying amount of sand seen between the trees which, in turn, is a function of the tree size and state of vegetation between the trees. As a result, some citrus gets classified as urban. The fact that this misclassification usually results in a scattering of urban characters, rather than a block, makes this problem less serious than it might seem. In fact, it has proven to be not much of a problem, since the urban normally shows in blocs; and we believe the results are accurate. It does require human intervention in the process, to indicate the known urban regions. This points out the need for human analysis and modification of the computer classification. We believe this feature always is needed but, in this case it is essential.

This method appears suitable for making a detailed land use map of the county, and we intend to do so.

Urban Features

Some characteristics of cities can be studied by means of computer classification maps. Such a map for the central part of Orlando is shown as Figure 3. Eight classes have been mapped: (1) industrial-new construction-bare sand, (2) commercial, (3) residential, (4) wooded residential, (5) undeveloped, (6) trees, (7) water, and (8) marsh. Major streets are drawn in manually on the basis of their visibility on this map and other computer maps. The pattern of major land uses is shown clearly, but the detailed information falls short of that provided by the more time-consuming conventional methods. An important distinction of this type of map relative to the conventional type is that the light reflectivity (and, in the case of the EREP multi-spectral scanner, thermal radiation) provide information

about the physical nature of the scene, while the planner usually needs to know also the economic and social characteristics of the scene, information which cannot be obtained directly from the satellite-produced map. However, the satellite-produced map seems to be an effective base, working from which the planner can obtain the additional information he needs in a selective way at reduced cost in personnel time.

Such a map delineates land use blocs well, so that on-the-ground observation often is needed only to verify or determine the nature of the use, greatly reducing the time required for ground observation.

The fact that the basis of distinction between land uses (or land cover) is based on light reflectance makes the dominant question become that of landscaping versus concrete and roof tops. Basically, then, for example, one bases his distinction between industrial and commercial uses on the relative amounts of bare sand, concrete and vegetation. A look at a few landscaped industrial areas and a few shopping centers that seem to be all asphalt convinces one of the difficulties of separating those two types of land uses. Hence, the separation between those two classes is not accurate. If they are combined into a single class, however, the reliability is improved at the expense of some loss of information content.

While the above characteristic represents a shortcoming from the viewpoint of conventional planning techniques, it represents an advantage in that it provides useful information on environmental features.

For those unfamiliar with computer mapping of satellite data, it should be pointed out that a character on the map corresponds to a resolution element of the sensor, about 60 by 80 meters, or .4 hectares (1.1 acres), for LANDSAT.

A simple random sampling of characters on this map and a similar map of a smaller city, when checked by the local planners against photography and their local knowledge, gives an overall accuracy of 86% for the eight classes shown. An accuracy of 90% is attained if the eight classes are reduced to six by combining the industrial and commercial classes, which cannot be reliably separated anyway, and by combining the two types of residential.

As discussed above, a computer map like this, while realistic, is too confused for many purposes. Hence, it is useful to produce a simplified map by tracing techniques, as shown by Figure 4. We believe this map has sufficient accuracy and detail to be of use to city planners, at least as a starting point for a more accurate map.

Advantages of handling data in digital form include the facility of numerical analysis, where appropriate, such as character counting to determine areas, and the flexibility in processing the data and presenting results. For example, once a classification has been made, it is relatively simple to prepare thematic maps of any of those classes or combinations of them. Such thematic maps present new perspectives and often are instructive and useful.

Orlando calls itself "the city beautiful", not without some justification, perhaps the primary justification being the numerous lakes and trees, made more evident when seen from above. A thematic map of Orlando lakes is shown as Figure 5.

A bonus from the classification is the distinction between residential types. The older residential sector located near the central business district, especially to the east of it, and extending into the affluent "bedroom suburbs" of Winter Park and Maitland has an abundance of large trees, so we have designated it as wooded residential. (Only the northeast quadrant of the city is shown.) This can be seen in Figure 4 and in the residential thematic map, Figure 6, where the dashed line is intended to delineate the sector which is predominately wooded residential. The new residential sectors, designated simply as residential, have fewer trees and can be seen in Figure 6 to form something of a ring around the core of the city. If one is interested in mapping the most desirable residential sectors, he might make a thematic map of lakes, trees, and wooded residential (northeast quadrant only): Figure 7.

An important type of thematic map is that showing industrial and commercial as a single class (southeast quadrant only shown): Figure 8. In addition to the central business district, this map shows a concentration of commercial activity at a large shopping center area (Colonial Plaza-Fashion Square) on east highway 50, heavy strip commercial along highway 50, scattered activity (much of it industrial) throughout the western half of the city, industrial and commercial activity along highway 441 leading northward out of the city, and strong activity, mostly commercial and new construction along highway 436 north of the city. This last activity is in rapidly developing Altamonte Springs--not only another city but also in another county (Seminole). A map such as this points out clearly that, regardless of political boundaries, the metropolitan area is an economic entity; and a unified planning program is needed.

It is interesting to use classification maps such as these to compare the development pattern of Orlando with the classic textbook patterns (1). Features of the Concentric Zone pattern are seen in the central business district, wooded residential, and non-wooded residential classes discussed above. Features of the Sector pattern are seen in the industrial sector directed outward from the central business district toward the northwest in the vicinity of U. S. highway 441, in the wooded residential sector extending northeastward into Winter Park and Maitland, and in commercial development along several major arteries. Multiple Nuclei features are some commercial centers (Colonial Plaza region, Winter Park central business district and Mall, Altamonte Springs commercial region), and industrial centers (e.g. the industrial park south of the city). In addition, in common with many other U. S. cities, Orlando can now be seen to have a partial "belt", which has some resemblance to the Concentric Zone feature. In this case, the belt is highway 436, running from McCoy Airport northward and then westward and having an associated buildup of commercial and high density residential development. The regions of rapid development are roughly equidistant from the central business district, with access aided by freeways, and with much of the development outside the taxing jurisdiction of the community which provides the reason for the development.

Another type of thematic map which is useful to planners is one which shows relative reflectance of the sectors of a city (density slicing of band 5), which may be regarded as intensity of development, Figure 9. Basically, this is a rough measure of the relative amount of concrete and rooftops visible from above(i.e. concrete versus vegetation). Generally, this pattern corresponds to that of the industrial-commercial map. One interesting additional area with relatively high reflectance is the rather large Pine Hills residential sector, which does not have many large trees. A map of this type can tell a planner what sectors of his city need attention.

Change-Monitoring

Probably the application which has created the most interest among planners to date is change-monitoring. A simple technique can be used, and the results appear useful. Usually, the process involves some method of comparing classification maps for the two dates of interest. Automated computer methods can be used, but our experience is that the reliability of classification is such that the human can more reliably detect changes by looking at the two maps overlayed on a light table. Figure 10 shows the results of comparing Orlando classification maps (northeast quadrant only shown) for two dates: September 6, 1972 and April 28, 1973, an interval of almost eight months. In this case, an 8-class map for the later date was compared to an industrial-commercial thematic map for the earlier date. We find that some human judgment is needed in comparing patterns. We do not feel that, at this stage of development, the results should be accepted without verification, which, however, is usually not difficult. At the time of this writing, 58 of the 90 changes noted have been checked by photography followed by ground observation where needed, and we feel fairly confident of nearly all of the interpretations and have found four definite errors, three of which are due to bad scan lines, a problem which is less serious with more recent data. This is two years after the second date; more prompt checking would reduce the difficulty and improve the accuracy of ground checking. When appropriate photography is available, its use can greatly reduce the amount of ground checking needed. This appears to be an effective and relatively inexpensive method of up-dating land use maps--perhaps even detailed maps of urban areas, although certain changes which do not involve appreciable land-clearing or addition of concrete surface or roof tops might be missed. The procedure needs further evaluation.

The period in this case was one of rapid development in the Orlando area, so the changes are more numerous than normal.

In addition to the up-dating of land use maps, this kind of map provides other benefits for the planner, such as showing him readily when specific land-clearing and construction jobs have begun, showing him the state of development of specific large projects, such as large residential developments, and giving him an overview which indicates the areas of highest development activity. This map, for example, shows major activity in three areas: (1) in the southwest quadrant, toward Disney World; (2) along the north-south portion of highway 436, where many new condominiums were being built, and (3) in Altamonte Springs (north of the city), where much commercial and residential development was occurring.

In addition to new developments, two other interesting changes are shown on the map: Two lakes were filled with silt at the second date and, therefore, do not appear as lakes. Lake Lawn, north of highway 50 was being dredged to fill in land for a park and its level lowered in a rejuvination procedure, and it appears as commercial. Lake Underhill appears as industrial, as it was filled with silt due to the East-West Expressway under construction through it at the time.

One portion of the East-West Expressway was under construction on the first date, and shows on the first map; another portion was under construction on the second date, and both portions show on that map.

CONCLUSIONS

On the basis of our experience to date, it is our opinion that computer classification, accompanied by human interpretation and manual simplification, can produce land use maps which are useful on a regional and county and, for special purposes, a city basis.

We believe change-monitoring to be potentially an effective application of such data at all planning levels.

At the present state of the art, caution should be used lest too much reliance be placed on strictly automated methods. Computer methods should be closely coordinated with human evaluation and checking, both because it improves effectiveness and because it increases "saleability" to the planners.

We have found that, generally, planners are interested in the possibilities; and most planning departments will cooperate by assigning one of their members to assist in preparing training samples and evaluating results. Collaboration by the planners also has the important effect of accelerating their acceptance of satellite data.

ACKNOWLEDGEMENTS

James J. Millard, of NASA Kennedy Space Center, has done the bulk of the programming of the computer programs used in this work and has been responsible for the computer runs.

Robert Stark and Scott Henderson, of the Orange County Planning Department, and Dale Smith, of the Orlando Planning Department, have collaborated by preparing training samples and checking results.

REFERENCES

1. F. Stuart Chapin, Jr.
Urban Land Use Planning
University of Illinois Press (1965)

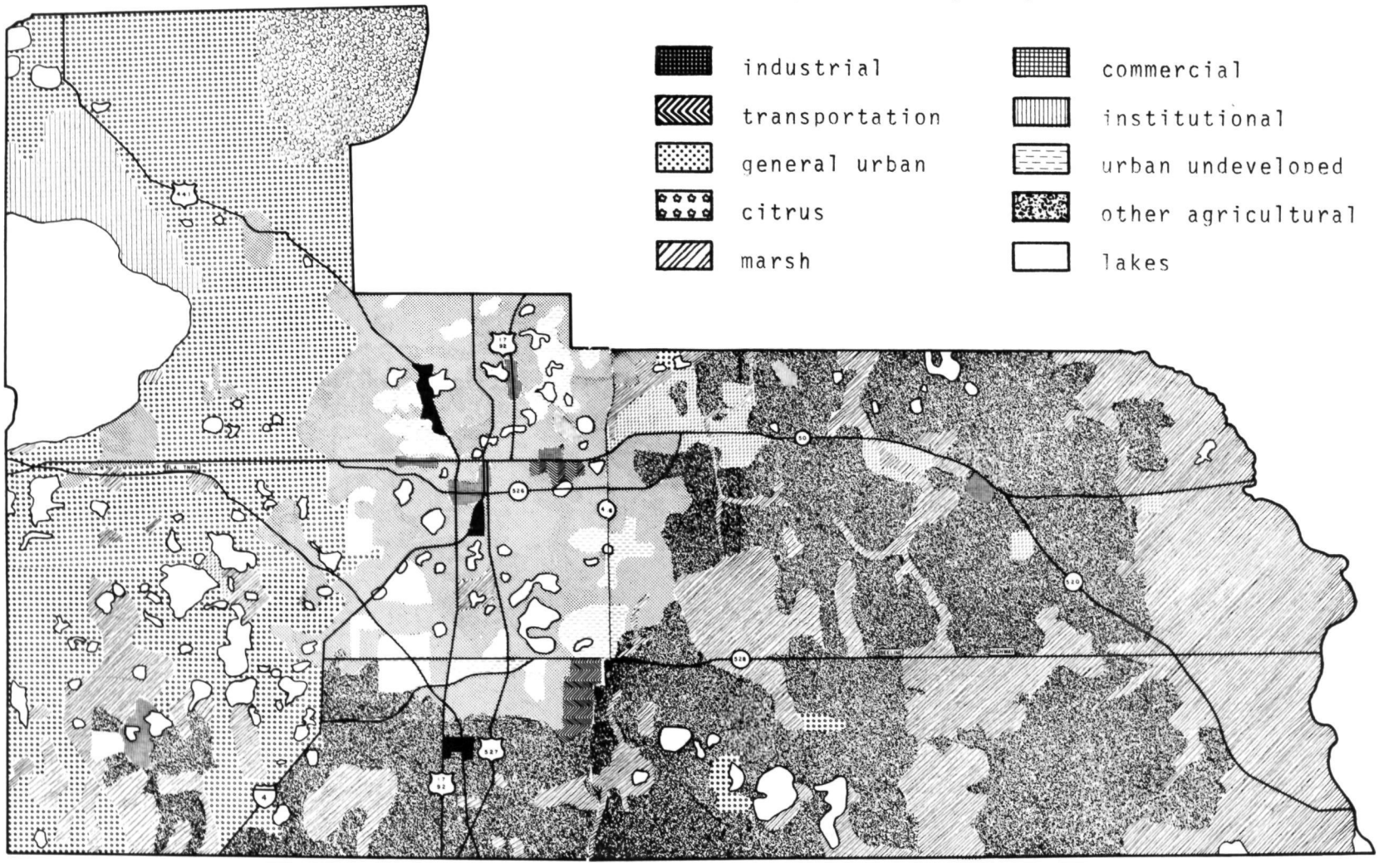


Figure 1. Orange County Generalized Land Use

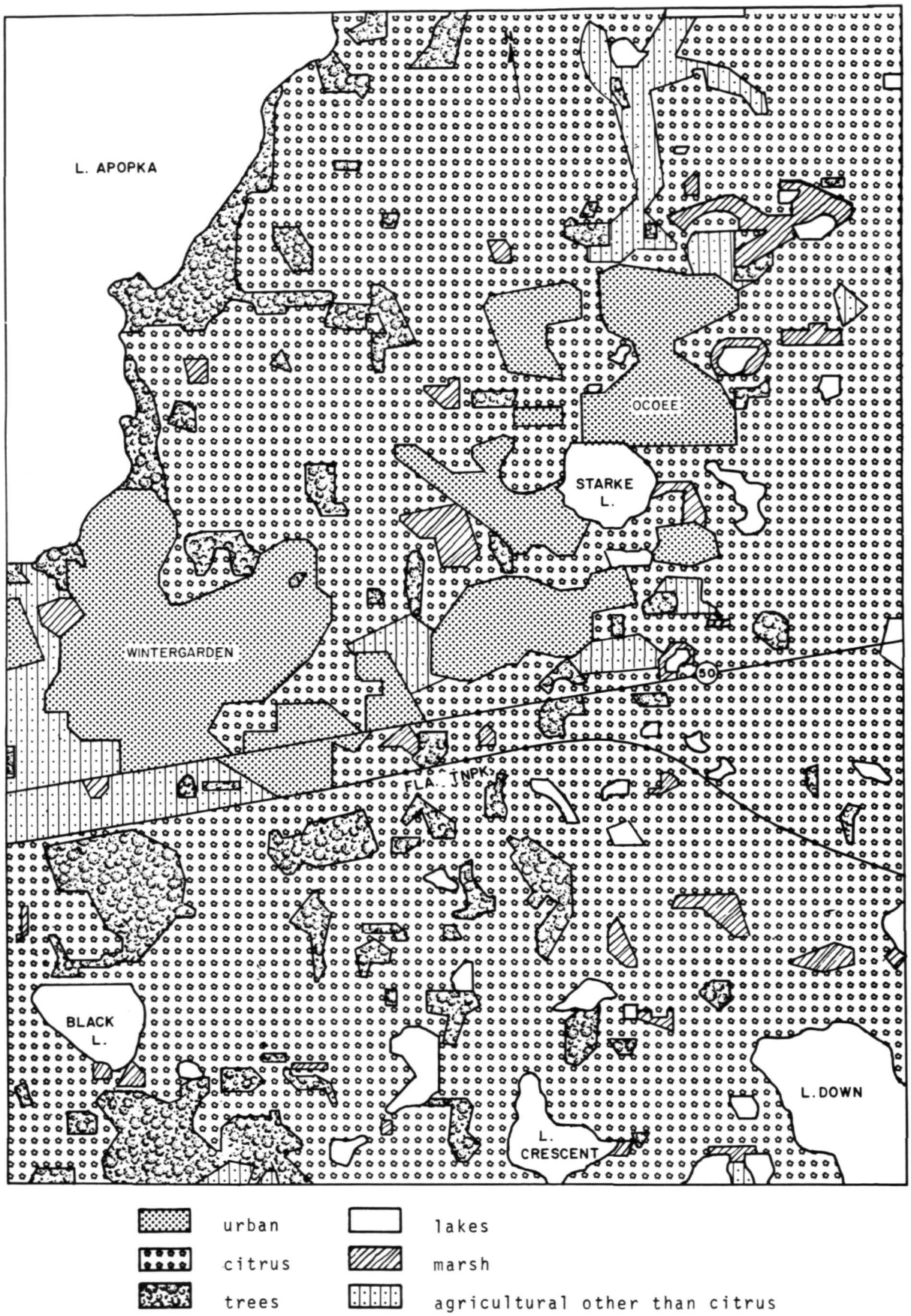


Figure 2. West-Central Orange County simplified from computer map 1674



B	industrial	T	trees
*	commercial	.	undeveloped
X	residential	S	marsh
/	wooded residential	blank	lakes

Figure 3. Central Orlando

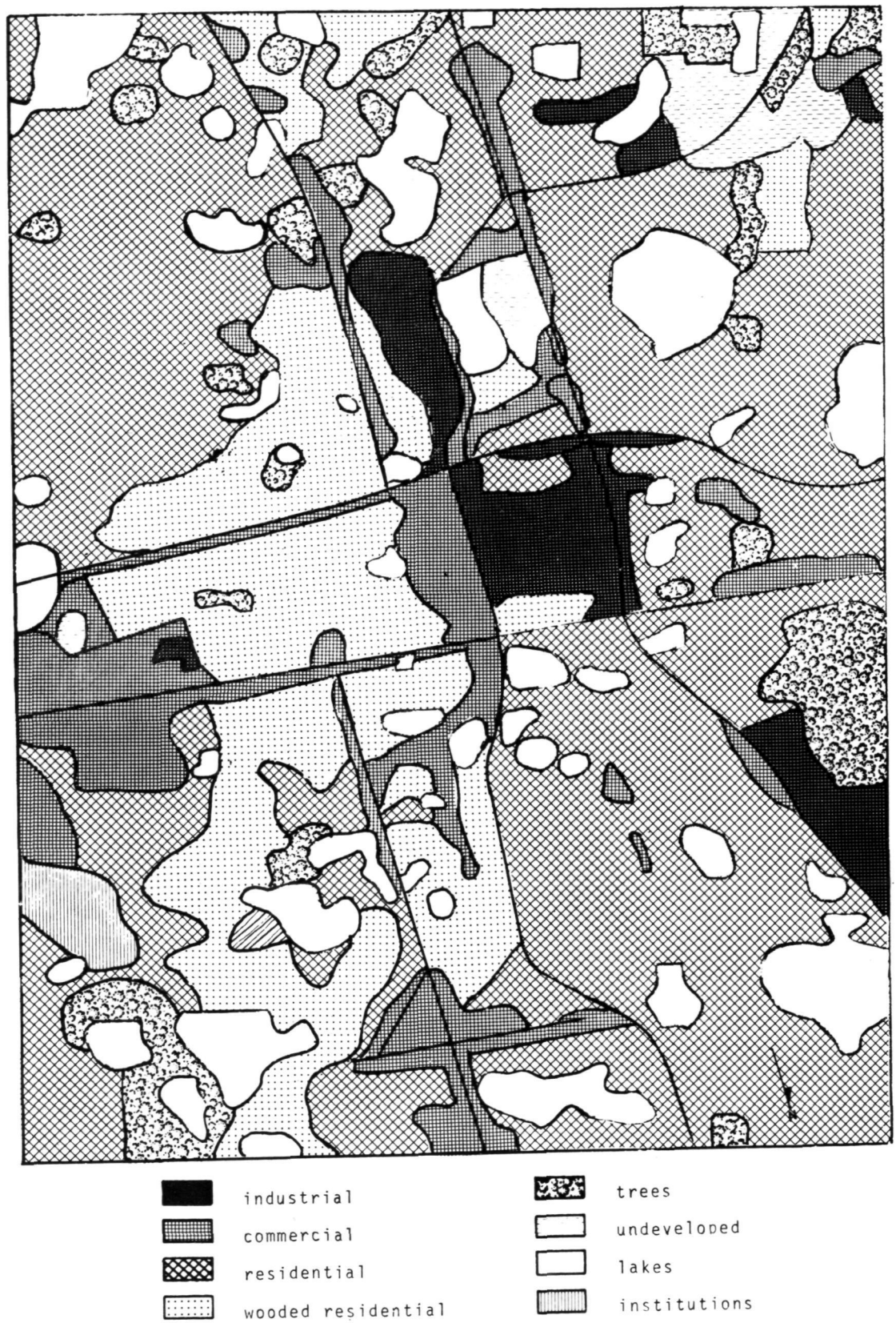


Figure 4. Central Orlando simplified from computer map

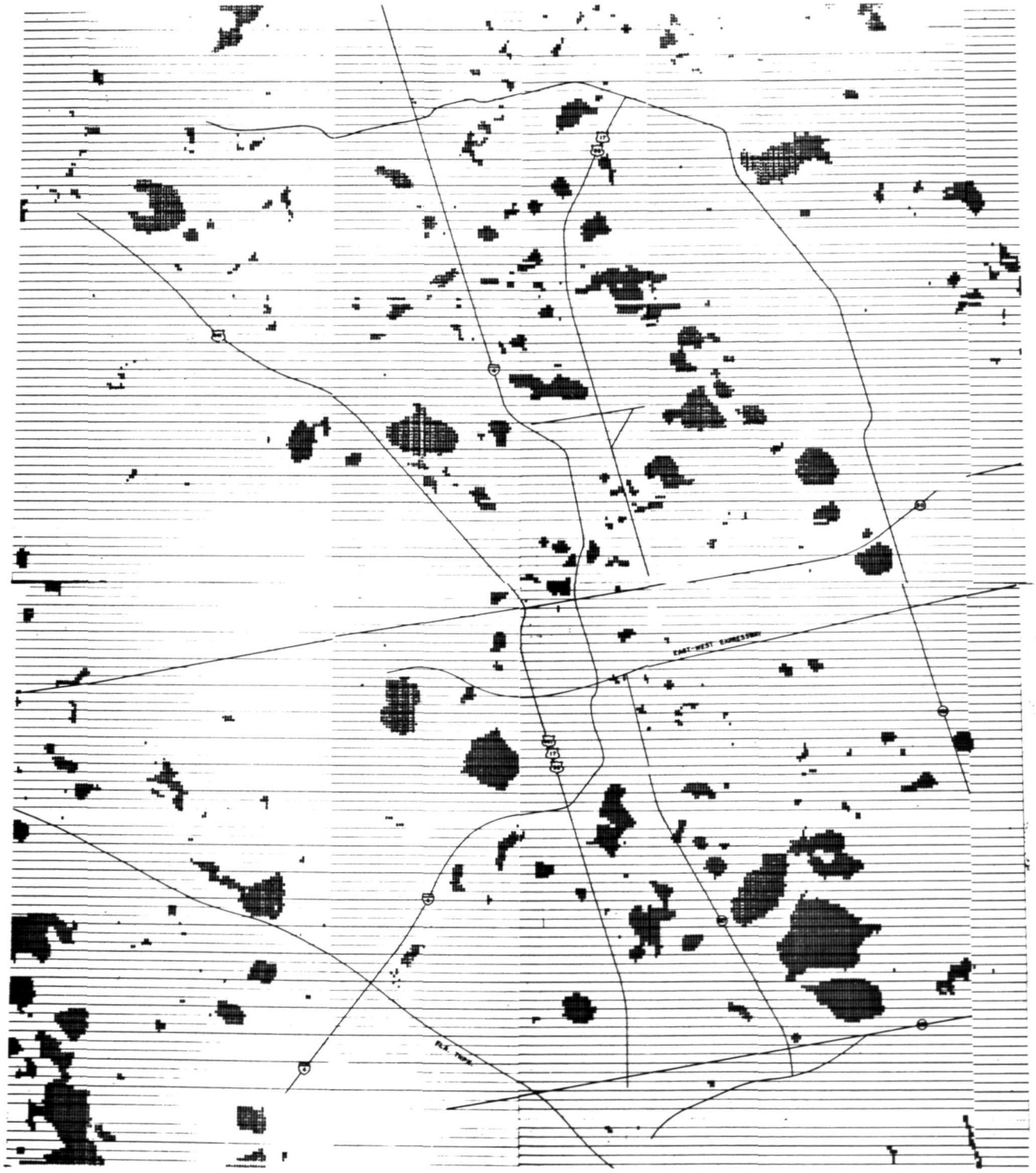
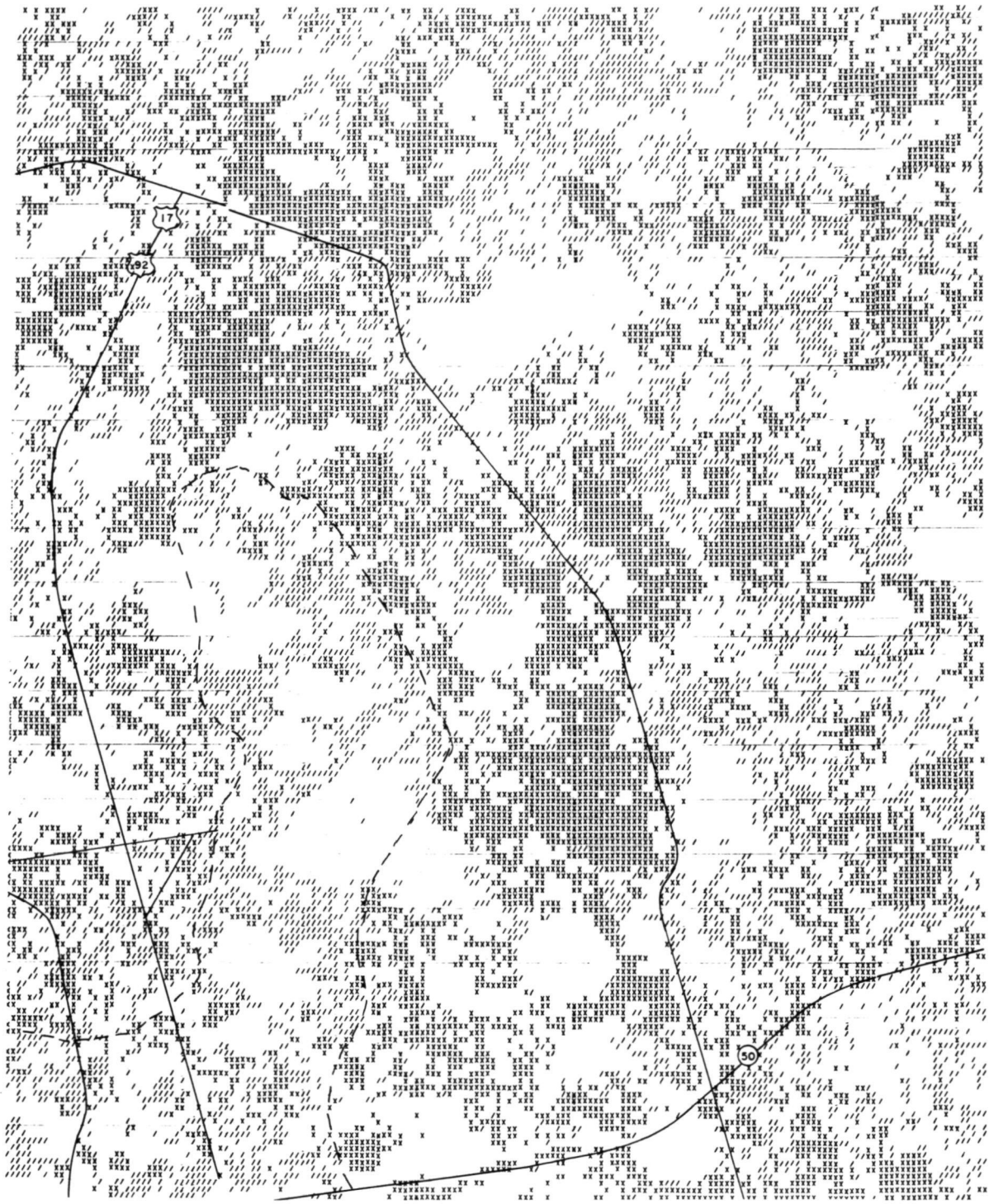
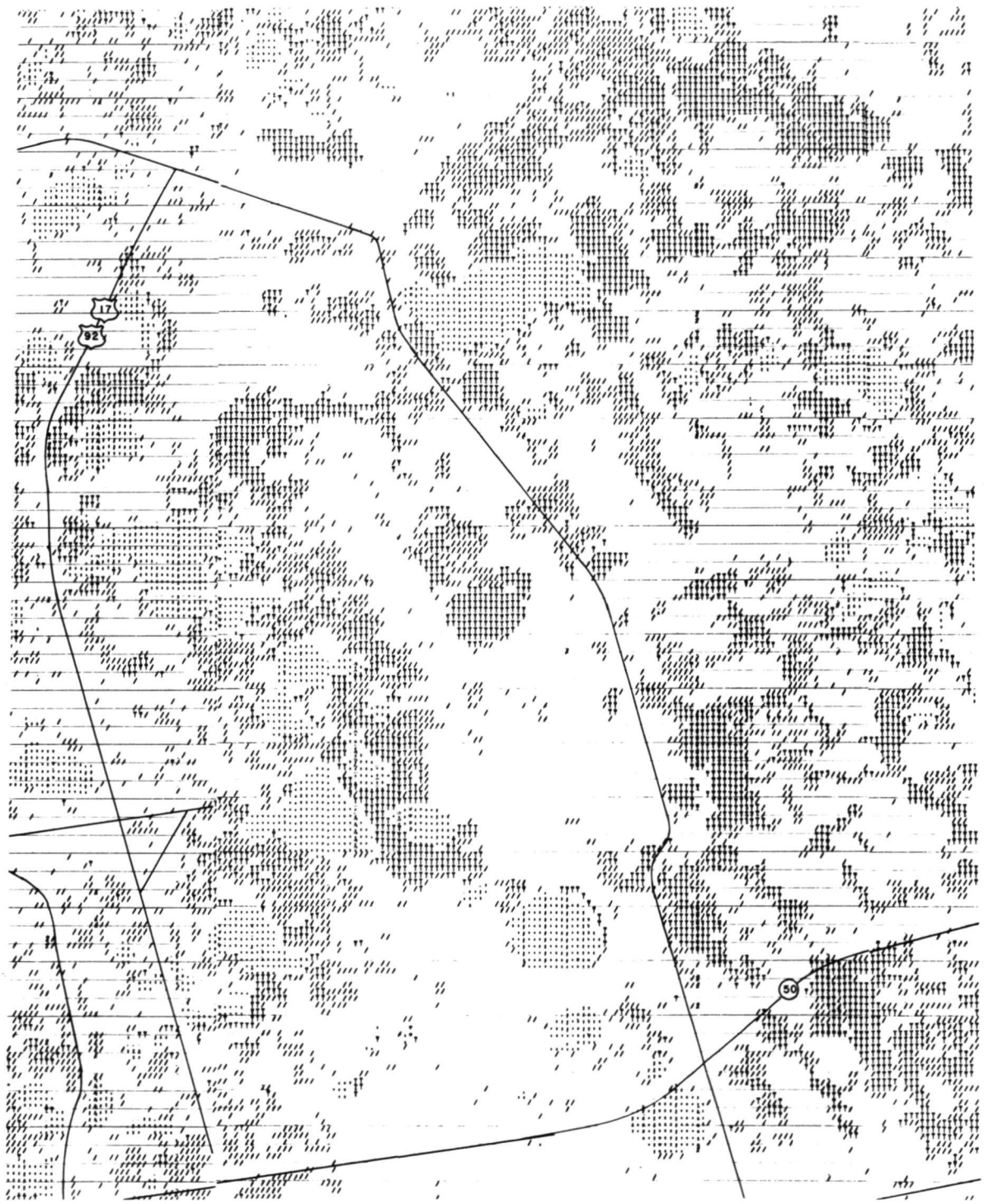


Figure 5. Orlando's Lakes



X residential
/ wooded residential

Figure 6. Residential thematic map of Orlando



/ wooded residential
T trees
. lakes

Figure 7. Thematic map of most desirable sectors of Orlando



B industrial-commercial
everything else blank

Figure 8. Thematic map of Orlando showing industrial and commercial land use as a single class



Figure 9. Intensity of development



Figure 10. Changes: September 6, 1972 to April 28, 1973

LAND USE AND ENVIRONMENTAL ASSESSMENT IN THE CENTRAL ATLANTIC REGION L-14

By Robert H. Alexander, Katherine Fitzpatrick, Harry F. Lins, Jr., and Herbert K. McGinty III, U.S. Geological Survey, Reston, Virginia

ABSTRACT

Data from high altitude aircraft, LANDSAT and SKYLAB have been used in a comprehensive regional survey of land use and its associated environmental impact in the Central Atlantic Regional Ecological Test Site (CARETS). Each sensor system has advantages that were demonstrated by producing experimental land use maps and other data products, applying them to typical problems encountered in regional planning and environmental impact assessment, and presenting the results to prospective users for evaluation. An archival collection of imagery, maps, data summaries, and technical reports has been assembled, constituting an environmental profile of the central Atlantic region. The investigation was organized into four closely-related modules, a land use information module, an environmental impact module, a user interaction and evaluation module, and a geographic information systems module. Results revealed a heterogeneous user community with diverse information needs, tending, however, definitely toward the higher-resolution sensor data and the larger-scale land use maps and related information products. Among project recommendations are greater efforts toward improving compatibility of Federal, State, and local land use information programs, and greater efforts toward a broader exchange of imagery, computer tapes, and land use information derived therefrom.

INTRODUCTION

The Central Atlantic Regional Ecological Test Site (CARETS) is a multi-disciplinary, multiagency experiment examining the three-component system "people--land use--environmental quality." The CARETS project has been funded cooperatively by the National Aeronautics and Space Administration (NASA) and the U.S. Geological Survey (USGS), agencies that are jointly seeking improved applications of space technology to the solution of environmental problems. The CARETS project approach has been the development of an experimental regional land use information system.

Land use and land cover data from high-altitude aircraft, LANDSAT, and SKYLAB are the primary inputs to the experimental information system. The intent of the experiment has been to build linkages between the technology and the users by assembling comparable data sets on land use, socio-economic factors relevant to land use planning, and environmental quality parameters. System design called for the flexibility of either aggregating basic data components to larger geographic areas, or presenting data elements in the most detailed form possible for smaller geographic areas. The test region was designed to be large enough to serve as a prototype for testing certain design and functional concepts that would be applicable to follow-on operational systems.

The purpose of this paper is to summarize on the occasion of the NASA Earth Resources Symposium, June 1975, the results of the CARETS project, just prior to the assembly of the products into final report format. This report thus serves both as a brief compendium of the 4-year project, and as a guide to the collection of detailed reports, maps, and other data products that will constitute the final reports of the CARETS project.

Characteristics of the Test Region

The CARETS region consists of the heavily-urbanized portion of the eastern seaboard, roughly the southern half of the region that has been called "Megalopolis" (1). The major cities of the test region include Philadelphia, Baltimore, Washington, Richmond, and Norfolk. Thus the region's character is both coastal and metropolitan, and extrapolation of results to other areas is considered most appropriate where one or both of those characteristics are present.

The size of the test region, 74,712 km^2 (28,846 mi^2) would place it between 40th and 41st in rank among the 50 states in area, and its population (13,404,558 in 1970) would place it between 2nd and 3rd in rank among the States in population. The experience gained in assembling land use and related environmental information for CARETS may be expected to be applicable to a populous State with a small area.

AREAS OF CARETS AND SELECTED STATES

State	Total Area Km^2	Rank
Indiana	93,491	38
Maine	86,027	39
South Carolina	78,283	40
CARETS	74,712	
West Virginia	62,341	41
Maryland	31,865	42

POPULATION OF CARETS AND SELECTED STATES, 1970

State	Population	Rank
California	19,953,134	1
New York	18,190,740	2
CARETS	13,404,558	
Pennsylvania	11,793,909	3
Texas	11,196,730	4
Illinois	11,113,796	5

Even in this highly urbanized region, the amount of land devoted directly to urban uses (residential, commercial, industrial, etc.) is small, though significant in its intensity of use and its impact on the surrounding land and water resources. Significant agricultural activity is present in the test region, especially in the Delmarva Peninsula east of Chesapeake Bay, in south-central New Jersey, in southern Maryland and in counties to the north of the Washington-Baltimore corridor, and in southeastern Pennsylvania. Vegetable farming, dairying, poultry, corn and hay are important agricultural activities and products.

Forest land is the dominant cover type in CARETS. In this region of heavy, but unequally distributed population, the significance of forest land is perhaps counted as much for watershed protection, wildlife preservation, recreation, and second-home developments as for supply of timber. Beaches, wetlands, and other coastal environmental types, though relatively small in area covered, are critical arenas of conflict among competing demands for residential, commercial, transportation, industrial, and recreational uses; and for conflict between all the above uses and preservation in the natural state.

Project Design and Organization

The CARETS investigation has been organized into four closely-related and integrated experiment modules: land use information module, environmental impact module, user interaction and evaluation module, and geographic information systems module.

The land use information module has employed three systems for organizing and quantifying remote sensor data for application to the environmental problems associated with land use in the test region. The first such system is complete land use and land cover mapping of the test region applying uniform classification criteria and common map scales for each coverage. Complete map coverages were produced for land use derived from high-altitude aircraft photography for 1970 at a scale of 1:100,000; for 1:100,000 land use change, 1970-1972, derived from high-altitude aircraft photography; and for land use derived from LANDSAT, mapped at 1:250,000. The second system employed consisted of the selected mapping of portions of the test region, using a variety of scales and levels of classification detail. The third system was spatial sampling for statistical assessments of accuracy and costs.

The environmental impact module was based upon linkages among land utilization processes and resulting effects on land, water, and air quality systems. Demonstrations representing selected portions of the test region employed measures of land use and measures of covariant phenomena such as air quality, streamflow characteristics, surface temperature and other components of the surface net radiation balance. Other demonstrated applications include the assessment of land use changes in coastal ecosystems, and the conducting of environmental impact studies.

The user interaction and evaluation module established and maintained contact with selected user institutions within the region. Conferences, workshops, and questionnaire interviews were employed to familiarize potential users with the range of products and services available or potentially available from such a system, and to receive feedback on usefulness with respect to agency functions. Data display and technical assistance were available at a regional information center for the CARETS investigation.

The geographic information systems module sought improved computer techniques for handling and quantifying the large amounts of information necessary for the land use and environmental impact modules. Since the system employed for extracting land use information from remote sensor data was a manual one, the intermediate products for further transferring the information were "line" or "polygon" maps. The project therefore sought a "polygon" system of digitizing and computer handling of these maps. Researchers used a USGS system, which was developing during the latter stages of the CARETS investigation, for testing the various software and hardware requirements. Volume digitizing and processing of the major CARETS maps, including overlay calculations, were performed by the Canada Geographic Information System, through a cooperative arrangement between the two governments.

The interrelations among the four experiment modules can be illustrated by reference to figure 1, the CARETS concept diagram. The land use information module consists of the four boxes in the upper left-hand portion of the diagram: the functions "remote sensor data input" and "land use data extraction," and the products "raw data, mosaics, indexes, and summaries," and "land use maps and area measurements." The environmental impact module is represented by the two lower left-hand boxes: the function "environmental impact assessment" and the products "other thematic maps, environmental impact analyses, and regional planning applications." Examples of the latter include reports showing relationships among land use and the various environmental quality factors studied. The user interaction and evaluation module is represented by the box on the right-hand side of the diagram.

The geographic information systems module is schematically represented in figure 1 by the arrows connecting the various functions and products. The topmost arrow, leading from the user module back to the remote sensing data input, represents the desired feedback to the design and operation of future remote sensing data-gathering systems--feedback that should result from this report and the reports of other investigators conducting similar studies of Earth resources applications of remote sensor data.

LAND USE INFORMATION MODULE

Remote Sensing Data Input

Remote sensing data from low-altitude aircraft, high-altitude aircraft, LANDSAT, and Skylab were acquired for periods of time ranging from 1959 to 1975. These data served as the basis for the extraction of systematic, quantified data sets on land use and land cover, by processes of manual photo

and image interpretation, and subsequent transferring of the interpreted units to a map or photomosaic base. CARETS interpreters used the remote sensing data mostly in the form of color or color infrared transparencies. Throughout its duration the project maintained the entire image or "raw data" collection, which served as a reference source for users and members of the research team alike. At the end of the CARETS project, these basic remote sensor data materials and the various maps derived therefrom will be transferred to an appropriate unit, in accordance with the recommendations to be made by the two sponsoring agencies. These basic data materials, along with the mission reports, index maps, and technical reports resulting from the efforts of this investigation, are expected to constitute a valuable environmental profile of the central Atlantic region, that will serve as a data base for future applications and research.

Basic Data Set: Land Use Mapping from High-Altitude Photography

In preparation for the basic mapping, researchers partitioned the region into 48 map sheets, each measuring 50 km on a side and keyed to coordinates of UTM Zone 18. They selected a basic mapping scale of 1:100,000 as one deemed economically feasible, given the size of the test region and the capabilities of the high-altitude aircraft photography.

The project initially produced a series of 1:100,000 geometrically rectified photomosaics as mapping bases on which to key remote sensor data to locations on the Earth's surface. Figure 2 presents an index to the location and names of the mosaics and the land use maps and overlays keyed to them. The USGS Topographic Division compiled these photomosaics from high-altitude aerial photography flown by NASA in October, 1970. To facilitate the location of features and keying to a computer storage system, the photomosaics are presented with a 1-km overlay grid. Figure 3 shows a reduced specimen of one of the photomosaic sheets. When researchers performed horizontal accuracy checks on these photomosaics, they found a conformance to within national map accuracy standards for 90 percent of the points checked.

The photomosaics and other map series have been placed on "Open File," the normal method of releasing reports and maps prior to or in place of final publication. Copies of these sheets are available for inspection at the USGS Public Inquiries Office, Room 1028, GSA Building, 19th and F Streets, N.W., Washington, D.C. 20240. There also, one can obtain the names of commercial firms that can make reproductions of these sheets.

CARETS interpreters employed a prototype land use classification scheme (table I), which was later slightly modified into the USGS Circular 671 classification (2). USGS Geography Program researchers also developed a Level III classification for possible use with remote sensor data, whose capabilities were tested during the CARETS investigation.

Using a manual photointerpretation process, a team of photo interpreters produced land use maps derived from the 1970 photography for each of the 48 sheets. These basic land use maps constituted one of the primary data sets for the experiment, both for user evaluation and for comparison with results to be obtained from LANDSAT and Skylab sensors. A reduced specimen of one of these land use maps, corresponding to the area of the photomosaic, is shown in figure 4.

Complete high-altitude aerial photo coverage was obtained again in 1972 for the test region. Comparing the 1972 photography with 1970 photography and 1970 land use maps, interpreters prepared a complete set of 1970-1972 land use change maps for all 48 CARETS sheets. They then labeled with two numbers each polygon identified as having changed. The first number represented the land use category before the change and the second the land use category after the change. A specimen of one of the maps showing land use change is presented in figure 5.

To facilitate the use of the land use data, the CARETS project produced a series of overlay maps for the region. To allow the association of land use information with drainage areas, maps of major drainage basins for the 48 sheets were compiled, keyed to the mosaics at a scale of 1:100,000. Figure 6 shows a reduced specimen of one of these sheets.

To test the usefulness of surficial geological information in association with land use data, researchers preapred a set of maps depicting landforms and surface materials for the Washington, D. C. and Norfolk-Portsmouth Standard Metropolitan Statistical Areas (SMSA's) and for five additional sheets in the southeastern Virginia area. A reduced specimen of one of these maps is shown in figure 7, and a key to the classification used is shown in table II.

Another regional data set for which land use comparisons were desired was the location and boundaries of geographic areas used by the Bureau of the Census for reporting population statistics. For all SMSA's within the test site the project compiled census tract maps keyed to the 1:100,000 scale photomosaics. For portions of the test region not inside SMSA's, sheets showing the location of county boundaries, also keyed to the basic map scale, were prepared. A reduction of a specimen sheet of one of the census tract maps is shown in figure 8.

Finally, overlays showing cultural features, place names, and transportation lines such as highways and railroads were prepared for each of the 48 sheets to provide locational cues for users of the land use and other data sets keyed to the same base map. Figure 9 presents a reduced specimen sheet of one of the cultural features maps.

Maps Derived from LANDSAT

For the land use mapping from LANDSAT imagery, investigators selected a scale of 1:250,000, based on a determination of geometric fidelity and spatial resolution of the imagery in the formats being used.

In the LANDSAT compilation, interpreters used color composite transparencies and existing USGS 1:250,000 scale topographic sheets as base maps. Figure 10 indicates the location and names of the 8-sheet series. A reduced specimen of one of the LANDSAT-derived land use maps is shown in figure 11. Although primarily mapped using Level I categories, the LANDSAT series includes 19 Level II and 4 Level III categories that could be identified from LANDSAT imagery.

Maps Derived from Skylab

The CARETS Skylab experiment utilized data obtained from the passing of Skylab 3 over a portion of the test region on August 5, 1973. These include photographic data from multispectral cameras (S190A) and from the Earth Terrain Camera (S190B). Of most interest to the investigators and the users of CARETS land use information were photographs from the S190B experiment, which were of sufficient spatial resolution to allow the identification of most of the Level II categories, and approached in capability the high-altitude aircraft photography. To assess the value of Skylab photographic data (S190B) as a land use mapping source, CARETS investigators compiled land use maps of the city of Fairfax, Virginia, both from high-altitude color infrared photography and from Skylab color photography. Researchers field checked and corrected the map derived from aircraft data to enable the measurement of the relative accuracy of the Skylab map by direct comparison. Using a systematic aligned sample they found the Skylab map to have an accuracy of 83 percent. Researchers found the S190B photography to provide relatively high-resolution data, which can be valuable for land use mapping and inventorying in urban as well as non-urban areas. Experience with various remote-sensor data users indicates that photography of the caliber of S190B could be of considerable value in the work of planning agencies at the State or regional level.

To allow a comparison of Skylab, LANDSAT, and high altitude aircraft photography data and CARETS map products, figures 12 to 21 present sample portions of imagery and maps at a consistent scale (1:100,000) that cover the same site, the Bowie, Maryland area of suburban Washington, D.C. Most of the maps are at their original scale. The imagery and some maps have been enlarged.

Other Maps at Various Scales

Researchers performed several mapping experiments using a variety of scales, to test procedures not employed in the standardized mapping of the entire test region. For example, a 1:1,000,000 scale map of "photomorphic regions" as derived from an uncontrolled LANDSAT black-and-white mosaic, produced a partitioning of the area into subregions of similar tones and textures. These "photomorphic regions" bore close resemblance to the categories mapped in the land use map in the National Atlas at a scale of 1:7,500,000 from data obtained many years before LANDSAT. If other environmental variables mapped at scales of 1:1,000,000 or smaller show similarity with patterns visible on LANDSAT imagery, LANDSAT may have additional value as a source of subregions for spatial sampling (3).

The large size of the CARETS area has limited other experimental mapping efforts to smaller test sites within the region. Foremost of these was the Norfolk test site, defined as the 1970 Norfolk-Portsmouth SMSA. Of great value in conveying to users the potential of remote sensing was a set of maps showing land use change from 1959 to 1970 in the Norfolk SMSA. Planners in particular were interested in seeing the display of the areas that had undergone change because of the greater environmental stresses placed on these areas of change. During the 11-year period, 184 km^2 (nearly 10 percent of the total test site area) changed from one Level I category to another. Of this change, 44 percent involved conversion from agricultural to urban uses.

In another Norfolk test site experiment, interpreters used 1:100,000 land use maps and LANDSAT color composite transparencies to detect 1970-1972 land use change at both Level I and Level II. In using 1972 high-altitude aircraft photography to verify the changes detected, investigators found instances of "false changes," those detected but not actually occurring. Many of these "false changes" can be accounted for by the different appearance of the terrain under different seasonal conditions (4).

A third Norfolk test site experiment involved the Level III land use mapping of the test site using high-altitude aerial photography at a scale of 1:100,000. The preparation of this map followed suggestions of users and of studies of the environmental impact of land use change, which indicated the requirement for greater detail than that provided by Level II.

The results of these and other experiments in the Norfolk test site have been compiled into one of the major reports of the CARETS project. This report will become part of the CARETS project final report.

Spatial Sampling for Accuracy Studies

The CARETS project exerted considerable effort in developing methods of measuring the accuracy of the various remote sensor-derived data sets that it evaluated. One way of assessing the accuracy of a new map is to compare it visually with another map of the same area accepted as "accurate." This visual comparison method is effective because the human eye and brain combine to make a very rapid and efficient processor of 2-dimensional data. But CARETS researchers desired a more objective and quantifiable method of comparing land use maps and assessing relative accuracy.

One method employed was to partition the land use map derived from remote sensor data into two categories: (1) areas where the interpreter had a high degree of confidence in his interpretation accuracy and (2) areas where the interpreter was unsure of the interpretation and that he marked as "questionable." Field checking determined that the areas of high interpreter confidence were also highly accurate in their classification. Areas of low interpreter confidence, on the other hand, were found to be inaccurate, 50 percent or more of the time. For the land use data set derived from high-altitude aircraft photography, researchers determined the correct classification of "questionable areas" by direct field verification to enable the use of this data set as a correct base against which to measure the accuracy of LANDSAT and Skylab interpretations.

The CARETS project also employed a comparison of classifications of sample points selected from each of two maps being compared, or from one map and ground or field observations from low-altitude aircraft.

A third method the project employed was a comparison of areas of each land or water category, as measured from each of the source data sets being compared. The use of this method, however, is contingent upon one's ability to measure satisfactorily the areas involved.

Major problems identified in the earlier CARETS accuracy assessments include:

(1) the mixture of different land use categories within a small area, which is the minimum-size mapping unit;

(2) the generalization of land surface types into units covering larger areas, as in lower-resolution sensors such as LANDSAT;

(3) errors due to imperfect registration of boundaries between categories on the maps being compared;

(4) errors due to generalization from larger map scales to smaller map scales;

(5) errors due to differences in interpreter applications of the classification system;

(6) residual errors due to interpreter misclassification;

(7) errors due to change between the times of the gathering of the two data sets.

After conducting the preliminary accuracy research, investigators undertook a comprehensive accuracy study using a stratified random sampling technique to select and obtain a variety of accuracy measurements. They used a 1-percent sample of the entire CARETS region, including 28, 5 x 5-km sample sites in non-urban areas and 15, 2 x 2-km sample sites from within urbanized areas as defined by the Bureau of the Census. The stratification into urban and non-urban categories resulted from the earlier studies that suggested different accuracy problems with the two kinds of areas.

CARETS investigators assessed the effect of generalization to smaller map scales using land use maps compiled at 1:24,000, 1:100,000, and 1:250,000, from the same remote sensing source (high-altitude aircraft photography), and field verification by ground or low-altitude aircraft observation or both. Preliminary results indicated lower accuracies than expected for a point-by-point comparison using a 1-km sample grid overlay on all the sample sites.

ACCURACY OF LAND USE CLASSIFICATION AT SAMPLE POINTS

FOR THREE SCALES, USING SAME SOURCE MATERIAL

Scale	Accuracy
1:24,000	85%
1:100,000	77%
1:250,000	73%

The above figures obscure the dependency of accuracy on the type of land use--the Level I categories at the three test scales.

COMPARISON OF ACCURACY OF LEVEL I INTERPRETATIONS AT THREE SCALES

Scale	Level I Category, Percent Correct Identification				
	1	2	4	5	6
1:24,000	79	88	91	98	72
1:100,000	80	83	83	88	67
1:250,000	69	75	79	78	72

Investigators also compared samples derived from Level I interpretations of LANDSAT imagery and Level I interpretations of high-altitude aircraft imagery at the same scale. They identified the Level I land use at the center points of each 1-km cell within each sample site on the LANDSAT- and aircraft-derived maps, and found the LANDSAT maps to have an overall accuracy of 70 percent as compared to the 77 percent accuracy for the maps from high-altitude photography at a scale of 1:250,000. The major land use types in discrepancy between the two maps were found to be in the urban and built-up area (Category 1). The following table illustrates accuracy as a function of Level I land use categories:

COMPARISON OF ACCURACY OF ERTS AND AIRCRAFT INTERPRETATIONS,

LEVEL I POINT SAMPLE

	Level I Categories, Percent Correct				
	1	2	4	5	6
Aircraft	69	75	79	78	72
LANDSAT	34	67	77	82	61

The results cited above are examples taken from a study not yet completed. The final results will be reported in one of the major sections of the final report.

Cost Factors

One of the desires of the CARETS investigation was to produce cost documentation and calculations so that the results could be quantitatively compared with those of other investigators, and so that cost factors could be available for use in planning and budgeting follow-on operational efforts. The difficulties of assessing and evaluating costs arise because of the complexity of the processes of extracting land use information, compiling maps, and delivering information products derived therefrom to users (a process that involved many intricately interwoven steps, most highly dependent on other steps in a sequence). Moreover, the monetary inflation occurring throughout the period of performance of the CARETS project increased costs in different proportions for different aspects of the labor and materials inputs. Nevertheless, the CARETS project has exerted considerable effort to present the cost information in as detailed a breakdown as possible, in anticipating the usefulness of at least some components of these cost data to readers of the final report. When comparing the accuracy of various data sets derived from different remote sensor systems, one should realize that different costs are associated with different levels of accuracy. Therefore a prospective user or developer of an operational land use information system should take careful account of tradeoffs between cost and accuracy. Greater accuracy can be obtained, up to a point, by greater investment in detailed data-collection and interpretation activities and in improved technology for obtaining and processing such data.

Two illustrations of documentation of costs of the CARETS project are presented in tables III and IV. Complete documentation of the effort will be presented in a cost section of the final report. Table III compares mapping costs (derived from sampling procedures described previously so that comparisons between cost and accuracy could be made) at each of the three scales tested: 1:24,000, 1:100,000, and 1:250,000. The costs to produce maps at these three scales from high-altitude photography are functions of several processes in the compilation, including acquiring the data, interpretation, preparations for reproduction, and reproduction and publication. Recognizing that actual operational experiences may be quite different from those of mapping 1 percent sample sites, investigators attempted to combine the operational and sampling figures through the experience obtained in mapping the entire CARETS region at a scale of 1:100,000, and using that experience to interpolate between costs of sample mapping at 1:24,000 and 1:250,000. The costs for data acquisition are those presently listed by the EROS Data Center at Sioux Falls.

The interpretation costs are based on an average per hour cost of $20.00. Table III shows that the cost of interpretation using the same source data at 1:24,000 is approximately 2 times that at 1:100,000, which in turn is approximately 1.2 times that of interpretation at 1:250,000. The cost of interpretation, however, is only a portion of the total cost to produce a land use map product.

Table IV summarizes cost estimates per km^2 for deriving land use maps at 1:250,000 from high-altitude aircraft photography and LANDSAT imagery. In this example, interpreters mapped land use using USGS topographic sheet, black and blue line color separation plates, as mapping bases. The project acquired imagery for each sensor at the mapping scale. The costs that differ for the two

involved those to acquire the aircraft photography and LANDSAT imagery, those to set up the mapping base, and those to complete the compilation. Table IV also lists standardized labor costs as $20.00 per hour. The time for compilation and cartography is based on the experience of the CARETS project, and the costs of reproduction and publication are estimated from other USGS experience. Table IV reveals that the cost to produce a Level I land use map from high-altitude aircraft photography amounts to approximately $0.48 per km^2. The cost to produce a comparable Level I map from aircraft photography is approximately four times the cost to produce a land use map from the lower-resolution LANDSAT imagery. The difference in the two, results primarily from the greater interpreter time needed to analyze the greater amount of detail on the aircraft photography.

A comparison of costs of producing the maps with accuracy percentages reveals that the range in accuracy difference is relatively small. The high cost of producing a land use map at 1:24,000 ($11.93/$km^2$) is not offset by the increased accuracy. Mapping at a scale of 1:100,000 in the rural areas is approximately twice as expensive as mapping at 1:250,000 using the same source materials. The accuracy at the larger scale is only slightly improved over the accuracy at the smaller scale. The decision to map at either 1:100,000 or 1:250,000, therefore, should depend upon the intended utilization of the maps.

ENVIRONMENTAL IMPACT MODULE

The environmental impact module of the CARETS investigation consists of several demonstrations illustrating the relationships among land use and various environmental factors or environmental quality measures. Results of these studies are presented in separate reports, which will be compiled as portions of the CARETS final report.

Air Quality

In the Norfolk test site the CARETS project conducted a study of the impact of land use patterns and area source control strategies on air quality. Compiling an estimated average of the annual winter area source emission from CARETS Level II land use categories (Level III was required for residential areas) and placing this inventory into a diffusion model, the investigators estimated sulfur dioxide emissions in the Norfolk-Portsmouth SMSA for 1972. Then using the Southeastern Virginia Planning District Commission's map of projected land use for 1985, they predicted sulfur dioxide emissions for 1985. The researchers predicted a measurable deterioration in sulfur dioxide levels if expected land use changes with their attendant expansion in area sources of air pollutants occur.

Predictions of Streamflow Characteristics

In research designed to evaluate the effectiveness of CARETS land use data in improving estimates of streamflow characteristics in selected drainage basins in Maryland, Delaware, and Virginia, investigators tested Level I and Level II land use categories from both aircraft and LANDSAT data. For

this study researchers selected 39 small drainage basins where stream gaging records were available. Portions of two of these basins (designated 5945 and 6495) are shown in figure 21. Comparison of figure 21 with figures 14, 15, 16, and 17 indicates the variety of types of land use within these particular basins. Other stations in the sample were less affected by urban development, and served as control stations to indicate stream behavior under more natural vegetation coverage. The investigators compared streamflow predictions made using a standard USGS multiple regression technique, with predictions made by adding regression terms incorporating area covered by the various land use types within the drainage basins. Preliminary results have indicated that significant improvements in the estimation of streamflow characteristics are obtained by adding the information from the land use measurements. These improvements result from use of data derived from both high-altitude aircraft photography and LANDSAT imagery. Implications of this work are that better information on streamflow characteristics might be made available to water resource planners and others, and at the same time costs reduced by reducing the number of gaging stations, if quantitative information on land use and land cover were available. Examples of results obtained in this study are shown in the following table:

PERCENT IMPROVEMENT OF PREDICTION OF STREAMFLOW CHARACTERISTICS,

USING LEVEL I LAND USE DATA FROM HIGH-ALTITUDE AIRCRAFT

Streamflow characteristic	Percent Improvement
Mean discharge, June	14
Mean discharge, July	20
Mean discharge, September	11
Mean discharge, November	17
7-day, 2-year low flow	13
3-day, 2-year flood volume	15
50 percentile discharge	26

Coastal Zone Management

Two studies illustrated applications of remote sensing and land use information to coastal zone management. In one, investigators examined the Atlantic coastal zone of CARETS with respect to the various land use and land cover categories identified, and illustrated how the natural processes in foreshore, dune, and back bay environments bring about differing responses to man's modification of these ecologically delicate landscapes (5). Investigators recommended more detailed land classification categories to improve the characterization of the various coastal types in terms of their stability or vulnerability to processes of man and nature.

The work of these researchers has already contributed to a major management decision by one of the agencies with coastal zone responsibilities. The National Park Service has decided to discontinue "protection" of seaward sides of barrier beaches from wave erosion, realizing that the protective actions formerly

taken interfered with the natural process of sand overwash and replenishment on the landward or lagoon side of the barrier islands. The land use and land cover information provided by CARETS indicates not only present locations of the man-modified types, but also serves as a data base to assess the effects of future modifications by nature and man.

A second study investigated certain environmental problems arising from land use changes in the city of Virginia Beach, Virginia. By examples from field observations, land use information derived from CARETS remote sensing sources, and other information provided by local planners, researchers explained how environmental problems such as barrier beach stabilization, beach replenishment in the commercial and hotel zone, and sewage disposal in urbanized areas have resulted from decisions made in the absence of full understanding of the coastal and wetland ecosystems that are vital to the well-being of the city

Compatibility with Geological Conditions

Researchers prepared a number of experimental surficial geologic maps, designated "landform and surface materials maps," to assist in the relating of land use to relevant surficial conditions such as the engineering characteristics of the near-surface materials. CARETS investigators expected that such information, keyed to the same mapping system as the land use maps, would aid planners in identifying characteristics most suitable from a geological and hydrological standpoint for future development of various land use types. Figure 7 presents a reduced specimen of one of these sheets in the coordination jurisdiction of the Metropolitan Washington Council of Governments (Washington SMSA). The key to the mapped categories is presented in table II.

Quality of Ground Water

A study conducted at the request of the Environmental Protection Agency investigated the uses of remote sensing for identifying the causes of man-made ground water pollution. Using examples of remote sensing data from the Norfolk test site, the investigators cite the complex chain of events that may lead to the pollution of ground water by man's activities, and the visible phenomena that can be observed by the remote sensors in a search for pollution indicators. Among the latter are the actual pollutants themselves, producers and activities that generate actual or potential pollutants, conditions associated with those activities, and surface cover types where one might expect to find detrimental activities, conditions, or pollutants. As a part of this study, researchers developed a special-purpose Level III land use classification and used it to map the Norfolk test site at a scale of 1:100,000.

Environmental Impact Statements

To inquire into ways in which CARETS products might be used to assist in estimating environmental impacts of proposed projects, as required by law, investigators reviewed the 150 environmental impact statements filed in the

CARETS region during a 4-year period. These statements fall into seven categories:

(1) construction of transportation and communication facilities;

(2) construction of power plants and power lines;

(3) urban renewal, new town development, and multi-story building construction;

(4) construction of watershed protection and development facilities;

(5) construction of waste treatment disposal facilities;

(6) navigation improvement and beach erosion control projects;

(7) establishment of conservation areas.

Land use data of the type produced by the CARETS project can be of assistance in developing portions of many of these impact statements. For such information to be of continuing value, it should be available operationally, in quick response to queries from the agency responsible for the environmental impact statement. Also, the existence of such a land use information system should be made widely known, as environmental impact statements are often written by consultants working under short deadlines and requiring quick access to whatever input data are required.

Land Use Climatology

The major CARETS project effort in studying the environmental impact of land use, and one that preceded the CARETS project as a NASA-funded investigation in the USGS, is a study of the surface energy balance and consequent climatological effects of man's local modifications of the land surface, as measured with the assistance of remote sensors. Although the concentration of effort has been the study of the urban heat island and other aspects of the climates of cities, the results have application as well to other types of land use, and the project has been given the generalized name of "land use climatology."

An integral part of this research effort has been the development and testing of an urban climate simulation model based upon the energy conservation equation (6). Each of the terms in this equation, net radiation, soil heat flux, sensible heat flux, and latent heat flux, is a complex function of certain environmental variables. Several of these variables (albedo, soil thermal properties, wet fraction, and aerodynamic roughness) are amenable to measurement and spatial analysis using remote sensor data. In this light, the CARETS Skylab investigation and its precursor aircraft mission have employed analysis of calibrated multispectral scanner data in constructing radiation maps of an urban area (the Baltimore test site) and in coupling this information with the operation of the urban climate simulator.

The precursor mission to the CARETS Skylab climatology investigation was flown by the Environmental Research Institute of Michigan aircraft, under

contract to NASA as support to this USGS project, over the Baltimore test site in May 1972. Researchers produced isorithmic maps of radiation temperatures derived from multispectral scanner data, which successfully showed the development of the urban heat island from sunrise to early afternoon. Also this research produced net radiation maps based in part on albedos determined from the scanner data. These maps, reflecting a single set of synoptic conditions, provided a base of observed environmental information against which the simulator was compared to see how well it could predict the climatic condition that occurred at that time. Results showed the simulator capable of providing close approximations to the energy balance conditions for specific land uses. In similar fashion, investigators analyzed thermal data obtained from the Skylab 3 mission. The results will appear in the final report of the Skylab portion of the CARETS project.

Using a modified version of the gray window model developed by R. W. Pease and applied during earlier NASA aircraft missions, researchers calibrated thermal data from the S192 multispectral scanner. The gray window model converts a radiant energy signal received at the scanner in space to its value when emitted by the Earth's surface by compensating for atmospheric attenuation (turbidity and water vapor) and for upward emitted radiant energy from the atmosphere. Researchers also used the scanner data to produce a map of thermal radiance values for the Baltimore-Washington area. A hand-colored version of this map is presented in figure 22. Preliminary results from this experiment indicate that land use-related components of urban climate can be measured and modeled with the aid of input data from spaceborne remote sensors. These results may have applications to urban land use planning, in making information on the climatological consequences of land use patterns in and around cities, available to input to future urban design. With energy shortages looming, opportunities to conserve energy inputs to urban heating and cooling systems may be welcome.

USER INTERACTION AND EVALUATION MODULE

The user interaction and evaluation module of the CARETS project was designed to obtain the input of local, regional, State, and Federal agencies and university and private research community users of land resource information into the development of a regional information system; to provide users with assistance and data resulting from CARETS research; and to have user organizations evaluate how well the CARETS products meet their needs.

On June 11, 1971, the USGS conducted a conference of potential users of land use data products at the National Academy of Sciences in Washington, D. C. This conference introduced the CARETS project to the user community, helped establish contacts with users, and provided insight into the land use data needs of agencies interested in land resources. User responses at this conference combined with results of prior technical evaluations led to the decision to establish the CARETS regional mapping scale at 1:100,000.

As the CARETS project progressed, CARETS investigators established an experimental regional information center in the Geography Program office to organize the user services role of the project and to maintain contacts with the user community. At the CARETS Information Center (CIC), visitors had access to remote sensor data and project products. The lack of funds and personnel to provide such services as imagery reproduction, search and

retrieval assistance and imagery interpretation assistance resulted in a reduction in the center's intended functions. The USGS's Public Inquiries Office's "Open File" system took on the responsibility of making map products available to users, but the complexity of the system discouraged many users from obtaining copies of the maps. Nevertheless, the CIC and the Public Inquiries Office provided services to numerous user agencies.

When most CARETS products were completed, investigators began the user evaluation phase of the project. In cooperation with the Metropolitan Washington Council of Governments (MWCOG) the CARETS project conducted an initial user evaluation workshop in March, 1974. At this workshop planners from MWCOG member agencies were introduced to the project and received a packet of sample products to be evaluated. The CARETS research group held a similar workshop for State and regional agencies and for Federal agencies in the fall of 1974. Approximately 2 months following the workshop, investigators conducted evaluation interviews with the representatives of the organizations attending the workshop.

The evaluation of CARETS land use and related products revealed that most user agencies interviewed at all governmental levels require more detailed data than those provided by the CARETS project. Table V presents the number of agencies (by major function) reporting utility in higher detailed Level III data. Level II data, though reported useful in support of agency functions by a majority of users interviewed and considered of high value by several user agencies, were generally considered of secondary utility by most users. Although such organizations as the Maryland Department of State Planning, the Virginia Division of State Planning and Community Affairs, the New Jersey Department of Natural Resources and Environmental Control, the Baltimore District of the Army Corps of Engineers, and several county, regional, and private organizations used the Level II land use maps in support of their functions, the greatest use for such data has been for display purposes or for providing a generalized view of land use.

Table VI summarizes the responses of user agencies toward products evaluated, revealing a highly positive response toward NASA-flown high-altitude aircraft photography and the USGS 7.5 minute orthophotoquads. Few agencies, however, found utility for the Level I LANDSAT-derived land use maps.

Recommendations resulting from the evaluation reflect the need to establish a flexible and reliable system for providing more detailed raw and processed land resource information as well as the need to improve the methods of making information available to users. Furthermore, some users expressed the need for the USGS to devote more effort toward educating potential users in the use of new data products.

GEOGRAPHIC INFORMATION SYSTEMS MODULE

The decision to develop a computer capability as an essential part of the CARETS project was based upon four considerations:

(1) Large amounts of land use information were needed in quantitative form for the environmental modeling and monitoring applications envisioned at the start of the project. This conclusion was derived from a number of studies, including one conducted for feasibility test and system design recommendations prior to the formal beginning of the CARETS project.

(2) A need existed for flexibility in land use information retrieval, by a variety of geographic areas and user jurisdictions.

(3) A need existed for area measurements and summaries for a variety of uses, including the previously cited work on stream basin charactistics.

(4) A need existed for quantitative comparisons between LANDSAT- and aircraft-derived land use data sets, according to the original project design.

All of these considerations led to the requirement that the data portrayed on CARETS maps be quantified for input to, processing, and output from, a computerized information system.

Selection of the Polygon System

CARETS project investigators obtained the advice of a group of consultants, the International Geographical Union Commission on Geographical Data Sensing and Processing. This group has wide knowledge and experience in the area of geographic information systems, including those having the capability of incorporating map or spatial data and retaining location on the earth's surface as an essential identifier for each data element. Investigators surveyed the available systems, hardware, and software and concluded that a grid system, though simpler to handle with present computer processing capabilities, would be too costly for handling the large amounts of input data, given the size of the CARETS region and the mapping scale and minimum mapping unit (4 hectares at 1:100,000). Therefore they decided to use a "polygon" type input system, in which the boundaries between land use categories, as drawn by the original interpreters, would be digitized directly and input to the system with as little loss in information as possible.

Since no capability existed within the USGS for volume digitizing of the number of maps required for CARETS, external digitizing capability was sought. After the issuing of a request for proposal and a thorough evaluation of proposals and capabilities, investigators decided to use the already operational capability of the Canada Geographic Information System (CGIS), Department of the Environment, Government of Canada. As of this writing, digitizing and processing of the CARETS data are approximately half completed by CGIS.

CARETS Tests in USGS as Part of In-House Information System Development

Shortly after the CARETS project began, investigators decided to develop an operational geographic information system for handling land use and related data in the Geography Program, USGS. In collaboration with the CARETS investigation, researchers conducted early tests contributing to the development of this new operational capability and making use of CARETS data and results of preliminary surveys of equipment and systems capabilities. Many of the information-handling capabilities desired as part of the CARETS project are being developed by the Geographic Information Systems Branch of the Geography Program for support of the new national land use mapping effort (Land Use Data and Analysis Program).

CARETS Information Systems Developments to Date

The CARETS project information systems effort was subject to a number of unavoidable delays, largely related to lengthy computer-services procurement actions, including contract negotiations between the governments of the United States and Canada. Work is proceeding satisfactorily, however, on digitizing (by means of the CGIS drum scanner) and data processing, including the capability of overlaying one polygon map with another, and calculating the areas of categories depicted on one of the maps compared to those on the other. At the time of the presentation at the NASA Earth Resources Survey Symposium, June 1975, CGIS has already delivered to USGS the complete results of processing land use data derived from LANDSAT maps for the entire test site, overlayed on county boundaries. This data set, which will be made available as a portion of the final report, contains measurements of each land use type as mapped by the interpreters, summed for each county and independent city within the CARETS region. Table VII presents sample Level I land use area summaries and percentages for the District of Columbia and for States or portions of States within the CARETS region.

Other processing will be performed on data from aircraft photography-derived land use maps for the Washington, D.C. and Norfolk-Portsmouth SMSA's and selected additional sheets. Other maps to be digitized for the two SMSA's include the 1970-1972 land use change, census tract, and landforms and surface materials maps, thus making possible the automatic correlations of data from the basic land use data set (1970) with those from these other data sets. Illustrations of these correlations and their applications will be presented in the final report.

In addition to the major digitizing and data-processing tasks, investigators are performing an experiment in interaction via computer graphics terminal, linked to the CGIS system at a remote location. Experimental output from this system is illustrated in the map (taken directly from CRT display) shown in figure 20. Derived from aircraft data, this map resulted from a query for location and amount of one type of land use only--in this case urban residential (category 11). Such a system is capable of a large number of possibilities of data processing and quick retrieval. Investigators believe that this capability will greatly enhance the value to many users of products derived from aircraft and satellite remote sensor sources.

CONCLUSION AND REOMMENDATIONS

In the CARETS project, each sensor system tested had advantages, which were demonstrated by producing experimental land use maps and other data products, applying them to typical problems encountered in regional planning and environmental impact assessment, and presenting the results to prospective users for evaluation. An archival collection of imagery, maps, data summaries, and technical reports has been assembled, constituting an environmental profile of the central Atlantic region, which will serve as a data base for future applications and research. Such products will also serve as a guidepost for investigating the design criteria of future operational land use information systems.

Responses of users revealed the heterogeneity of the user community and hence the difficulty of finding standardized products such as land use maps that were broadly applicable to user needs. LANDSAT data and 1:250,000 maps derived therefrom satisfied few of the users, but the relatively low cost for the regional-scale land use overview suggests the appropriateness of LANDSAT products for users with that particular need. Low-cost methods for user access to LANDSAT computer-compatible tapes would have increased user interest. Skylab high-resolution (S190B) photography was closer to aircraft photography than to LANDSAT imagery in capability and would have satisfied a number of potential users, but its one-time and limited areal coverage was a handicap in securing adequate user response.

The preliminary recommendations are summarized as follows:

(1) The most useful single product for CARETS users of land resource information is the high-altitude aircraft color infrared photography. Its potential for supplying the diversity of information required by users far exceeds the use made in the standard CARETS maps at 1:100,000. In the CARETS metropolitan areas, 1:100,000 maps are marginal for many users at the land use decision-making level. They are also of marginal value for those who need to evaluate specific environmental impacts. Such users need maps at a scale no smaller than 1:24,000, a scale well within the capability of the high-altitude photography. Therefore such imagery and maps should be included in a metropolitan land use information system if present users' needs are to be met.

(2) Lower-resolution imagery and smaller-scale maps are useful for certain users who are engaged in large-area overview surveys, not requiring information input at the land parcel or household unit. Speed and cost factors may justify use of such products in addition to the more detailed products needed in metropolitan areas.

(3) Value of remote sensing data and maps at all levels of detail would be increased if such information could be provided operationally on a regular basis.

(4) Archival imagery and computer-compatible tapes should be made easily available to users at a variety of levels of sophistication.

(5) A post-Skylab thermal capability is needed, along with improved methods of processing and mapping multispectral data, to capitalize on the promising prospects, indicated by the Skylab experiment, for delimiting urban heat island and other ramifications of altered surface energy regimes resulting from changing land use and land cover patterns.

(6) Much more effort is needed to improve compatibility of Federal, State, and local land use information programs and to facilitate exchange of imagery, computer tapes, and land use information derived therefrom. This recommendation arises from the observation that many different land use data collection and mapping programs are being conducted simultaneously, given the present near-autonomy of most land use user agencies.

REFERENCES

1. Gottmann, Jean, 1961, Megalopolis: the urbanized northeastern seaboard of the United States: New York, Twentieth Century Fund, 810 p.

2. Anderson, J. R., Hardy, E. E., and Roach, J. T., 1972, A land-use classification system for use with remote-sensor data: U. S. Geol. Surv. Circ. 671, 16 p.

3. Alexander, R. H., 1973, ERTS regional-scale overview linking land use and environmental processes in CARETS: Symposium on significant results obtained from the Earth Resources Technology Satellite-1, New Carrollton, Maryland 1973, v. I, sec. B, p. 931-937.

4. _____, 1973, Land use classification and change analysis using ERTS-1 imagery in CARETS: Symposium on significant results obtained from the Earth Resources Technology Satellite-1, New Carrollton, Maryland 1973, v. I, sec B, p. 923-930.

5. Dolan, Robert, Hayden, B. P., and Vincent, C. H., 1974, Shore zone land use and land cover Central Atlantic Regional Ecological Test Site: U. S. Dept. Interior, Natl. Park Service and U. S. Geol. Surv., Natural Resources Rept. No. 8.

6. Outcalt, Samuel, 1972, A reconnaissance experiment in mapping and modelling the effect of land use on urban thermal regimes: Jour. Appl. Meteorology, v. 11, p. 1369-1373.

TABLE I --LAND USE CATEGORIES IN THE CENTRAL ATLANTIC REGIONAL ECOLOGICAL TEST SITE DATA BASE

Level I Categories and Map Notation Used	Level II Categories and Map Notation Used
1 - URBAN & BUILT UP	11-Residential 12-Commercial and services 13-Industrial 14-Extractive 15-Transportation, communications, and utilities 16-Institutional 17-Strip and clustered settlement 18-Mixed 19-Open and other
2 - AGRICULTURAL	21-Cropland and pasture 22-Orchards, groves, bush fruits, vineyards, and horticultural areas 23-Feeding operations 24-Other
4 - FORESTLAND	41-Heavy crown cover (over 40%) 42-Light crown cover (10% to 40%)
5 - WATER	51-Streams and waterways 52-Lakes 53-Reservoirs 54-Bays and estuaries 55-Other
6 - NON-FORESTED WETLAND	61-Vegetated 62-Bare
7 - BARREN LAND	72-Sand other than beaches 73-Bare 74-Beaches 75-Other

TABLE II--LANDFORMS AND SURFACE MATERIALS CLASSIFICATION LEGEND

LANDFORMS-Digits 1 and 2		
No Slope, No Relief	Water	00
	Marsh, swamp	01
	Bogs	02
	Beaches	03
Little Slope, Small Relief	Flats, undissected	11
	Flats, dissected	12
	Flood plains	13
	Terraces	14
Gentle to Steep Slope, Moderate Relief	Sand dunes	21
	Hills	22
	Low Ridges	23
	Valley sides	24
	Gulley sides	25
Steep Slope, High Relief	Ridges	31
Negative Relief	Sinkholes	62
	Crater lands	64
	Vertical pits	66
Man-Made Features	Made land (fill)	81
	Sanitary landfill	82
	Waste (mine)	83
	Quarries, pits	84
Miscellaneous	Mined-out areas	91
	Unstable slopes	92

LITHOGRAPHY-Digits 3 and 4 (Bedrock more than 9 feet below the surface)		
Unconsolidated Deposits	Water	00
	Clay, silt	01
	Sand	02
	Gravel	03
	Boulders	04
	Colluvium	05
	Talus	06
	Organic	07
Igneous Rocks	Granite	11
	Gabbro, diorite	12
	Basalt, diabase, felsite, rhyolite	13
Metamorphic Rocks	Phyllite	21
	Schist	22
	Gneiss	23
	Quartzite	24
	Metabasalt	25
	Marble	26
	Slate	27
	Serpentine	28
Sedimentary Rocks	Shale, siltstone, mudstone	30
	Sandstone	31
	Conglomerate	32
	Limestone, dolomite	35

MISCELLANEOUS DESCRIPTORS-Digits 5 and 6	
High water table	01
Shallow soil (bedrock less than 9 feet below surface)	11

TABLE III-- PRODUCTION COSTS* PER KM^2 FOR LEVEL II LAND USE MAPS** AT THREE SCALES

	1:24,000	1:100,000	1:250,000	
Data Acquisition[1]	$.14	$.06	$.05	[1]Based on 50 frames for 10,000 km^2 1:24,000 ea. frame $28.00 1:100,000 ea. frame $12.00 1:250,000 ea. frame $10.00
Mosaic Construction[2]	$6.00	$.70	$.16	[2]Based on average estimate for mosaic construction by the Topographic Division (Interview with Bernard Kelley, USGS Topographic Division, 4/11/75)
Interpretation & Edit[3] ($20/hr)	600 hrs/ 10,000 km^2 $1.20	300 hr/ 10,000 km^2 $.60	250 hr/ 10,000 km^2 $.50	[3]Actual time from interpreting at 1:100,000 - estimates at 1:250,000 and 1:24,000 interpolated from sample site interpretation. Cost estimates based on USGS Topographic Division per hour rates, 1975.
Cartographic[4] ($12/hr)	200 hr/ 10,000 km^2 $.24	100 hr/ 10,000 km^2 $.12	80 hr/ 10,000 km^2 $.096	[4]Based on actual time for cartographic work at 1:100,000 interpolated to 1:24,000 and 1:250,000, and assumed to be 1/3 the interpretation time
Marginalia[5]	$1.25	$.08	$.010	[5]Based on actual costs to compile collars for CARETS maps at 1:100,000, and assumed to be the same per map at each scale
Reproduction[6]	$.10	$.01	$.002	[6]USGS cost to produce positive film transparencies at scale
Publication Cost[7]	$3.00	$.18	$.06	[7]Cost of publication by the USGS (Interview with Bernard Kelly, USGS Topographic Division, 4/11/75)
TOTAL	$11.93	$1.75	$.88	

*1975 dollars

**At scales and formats conforming to the USGS 1:24,000 and 1:250,000 topographic map series and CARETS 50 x 50 km 1:100,000 photomosaics.

TABLE IV--COMPILATION AND PUBLICATION COSTS* PER KM^2 FOR A LEVEL I LAND USE MAP**

	High-Altitude Photography 1:250,000	LANDSAT 1:250,000	
Data Acquisition from EROS D.C.[1]	$.05	$.01	[1]Based on 50 frames of high-altitude photography for 10,000 km^2 1:250,000 (4" x 5") at $10 ea. and a Cibachrome transparency from commercial firm at $41.50 (20" x 24") of LANDSAT
Mapping Base/ no mosaic[2]	$.15	$.01	[2]Based on rectified high-altitude photography with a transparency of the black and blue line plate at 1:1250,000, and on LANDSAT Cibachrome print with a transparency of the black and blue line plate: 5 1:250,000 high-altitude prints $10 ea. $10,000/50,000$km^2$=$.05/km^2 5 frames rectification $20 ea. $100/10,000 km^2=$10/km^2 1 line base map $20 ea. $20/20,000 km^2=$.001/km^2
Interpretation $20/hr[3]	80 hr/10,000 km^2 $.16	15 hr/10,000 km^2 $.03	[3]Interpretation time, estimated for interpretation from high-altitude photography and actual time for LANDSAT interpretation
Cartographic $12/hr[4]	40 hr/10,000 km^2 $.05	8 hr/10,000 km^2 $.01	[4]Cartographic time considered to be half the interpretation time, at Level I mapping
Marginalia[5]	$.01	$.01	[5]Based on the actual costs to compile collars for CARETS maps at 1:100,000 and assumed to be the same per map at each scale
Reproduction[6]	($18/sheet) $.01	($18/sheet) $.01	[6]USGS cost to produce positive film transparencies at scale
Publication Cost[7]	$.06	$.06	[7]Cost of publication by the USGS (interview with Bernard Kelley, USGS Topographic Division, 4/11/75)
TOTAL	$.48	$.12	

* 1975 dollars
** conforming to the USGS 1:250,000 map series

TABLE V--CARETS USER AGENCY LAND USE DATA GENERALIZATION REQUIREMENTS

MAJOR AGENCY FUNCTIONS	Number of Agencies								
	Level I			Level II			Level III		
	Primary Utility	Secondary Utility	Tertiary Utility	Primary Utility	Secondary Utility	Tertiary Utility	Primary Utility	Secondary Utility	Tertiary Utility
Land Use Planning (20)	0	1	4	3	12	0	18	0	0
Transportation Planning (5)	0	0	0	0	2	0	4	0	0
Environmental Protection	0	0	0	1	4	0	4	0	0
Mineral/Energy Survey (3)	0	0	0	0	1	0	3	0	0
Disaster Warning Assessment (2)	0	0	0	0	0	0	2	0	0
Water Resource Planning (2)	1	0	0	0	2	0	2	0	0
Fish & Wildlife Management (2)	0	0	0	0	2	0	2	0	0
Agricultrual Management (2)	0	0	0	1	1	0	2	0	0
Socio-Economic Data Collection (1)	0	0	1	0	1	0	7	0	0
Utility Planning (1)	0	0	0	0	1	0	1	0	0
Economic & Community Development (2)	0	0	0	1	1	0	2	0	0
Multi-Purpose Resource Managment (2)	1	0	0	0	1	0	1	0	0
Total (47)	2	1	5	6	28	0	43	0	0

*Excludes organizations primarily engaged in research and agencies not having an actual need for such data.

Numbers in parentheses indicate number of agencies participating.

TABLE VI --PRODUCTS REPORTED USEFUL IN SUPPORT OF AGENCY FUNCTIONS

Number of Agencies Finding Products Useful

	High-Altitude Photography	Skylab Photography	LANDSAT Imagery	Photomosaic	Level II Land Use Map, 1:100,000	1970-72 Land Use Change, 1:100,000	Census Tract & Political Boundary Overlay	Cultural & Locational Features Overlay	Level I Land Use, LANDSAT-Derived, 1:250,000	Landforms & Surface Material Map	USGS Orthophotoquads	Orthophotoquad Land Use Overlay	LANDSAT Gridded Image	Computer Plots of Land Use	Computer Data Listings
Washington Area Local Planning Agencies (11)	11	*	1	7	10	10	3	3	1	9	11	*	*	9	9
Regional Planning Agencies (5)	5	0	4	3	4	4	3	3	4	4	2	1	1	1	3
State Agencies (22)	12	7	9	11	14	12	8	6	4	8	11	10	6	10	10
Federal Agencies (21)	17	7	6	7	12	12	5	4	2	7	13	4	1	4	11
Research and University Community (6)	5	3	3	2	2	3	1	1	0	2	2	2	0	1	2
TOTAL	50	17	22	23	32	31	17	14	10	21	28	17	8	16	27

*Products not evaluated by local planners.

Numbers in parentheses indicate number of agencies participating.

TABLE VII--CENTRAL ATLANTIC REGION LEVEL I 1972 LAND USE AREA SUMMARIES DERIVED FROM LANDSAT IMAGERY DIGITIZED BY THE CANADA GEOGRAPHIC INFORMATION SYSTEM

		1 Urban	2 Agriculture	4 Forest	6 Wetland	7 Barren	Total Land	Total Water	Total Land & Water
Delaware	Km^2	321.6	2846.7	1599.7	322.6	.7	5091.3	1102.2	6193.5
	% Land Area	6.3	55.9	31.4	6.3	0			
D.C.	Km^2	138.0	0	20.6	0	0	158.7	10.3	168.9
	% Land Area	87.0	0	13.0	0	0			
Maryland*	Km^2	1844.3	10170.0	8767.4	612.0	18.7	21412.5	6054.5	27466.9
	% Land Area	8.6	47.5	40.9	2.9	.1			
New Jersey*	Km^2	1150.2	2830.7	4666.5	851.6	0	9499.0	1682.5	11181.4
	% Land Area	12.1	29.8	49.1	9.0	0			
Pennsylvania*	Km^2	1279.1	3150.3	1203.1	0	0	5632.5	59.5	5692.0
	% Land Area	22.7	55.9	21.4					
Virginia*	Km^2	1840.0	9459.3	20485.3	637.0	54.5	32476.0	6782.5	39258.5
	% Land Area	5.7	29.1	63.1	2.0	.2			
TOTAL	Km^2	6573.2	28457.0	36742.5	2423.2	74.0	74269.9	15691.4	89961.3
	% Land Area	8.9	38.3	49.5	3.2	.1			

* Includes only portion of State within CARETS region.

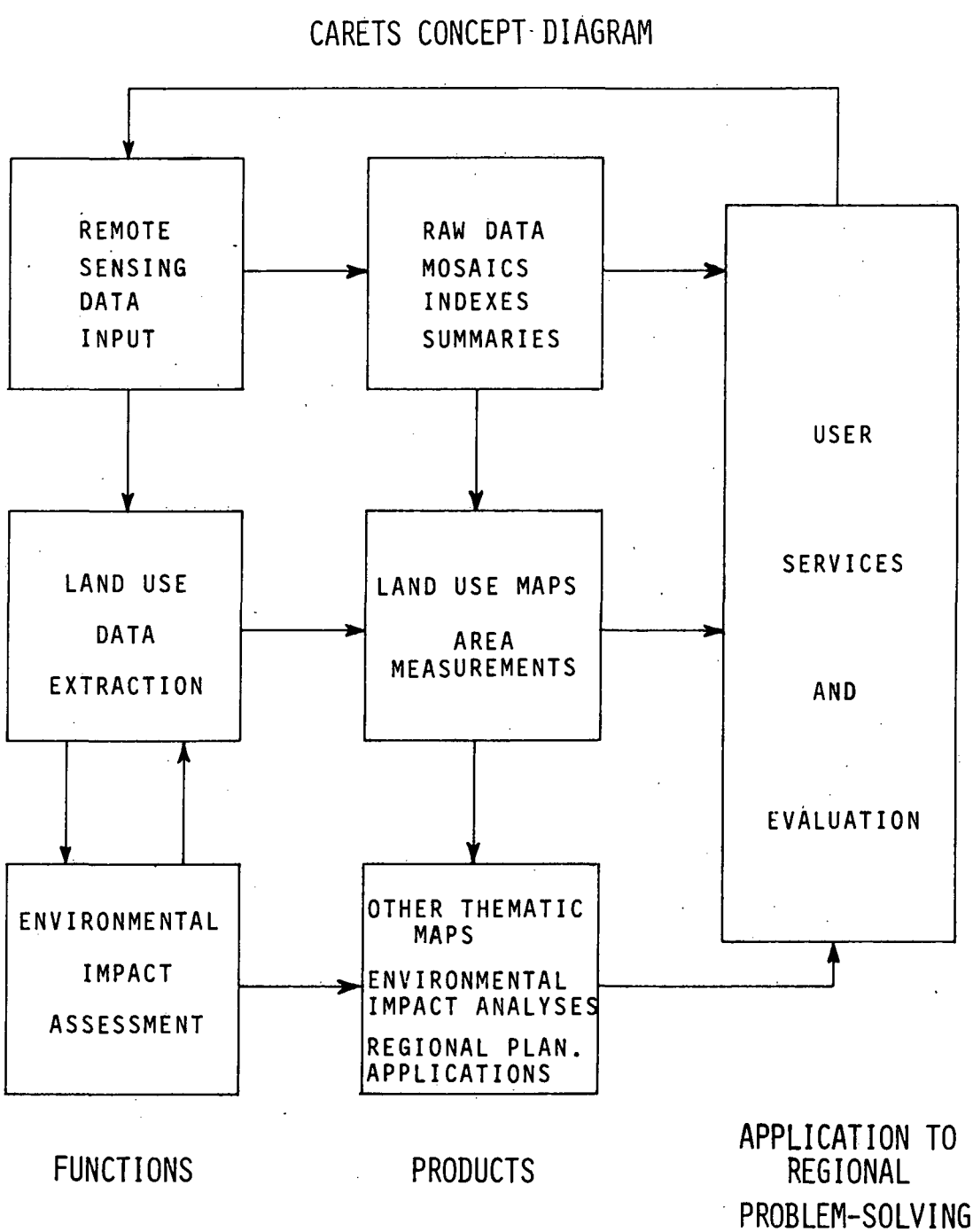

CARETS CONCEPT DIAGRAM
REMOTE SENSING DATA INPUT
RAW DATA MOSAICS INDEXES SUMMARIES
USER SERVICES AND EVALUATION
LAND USE DATA EXTRACTION
LAND USE MAPS AREA MEASUREMENTS
ENVIRONMENTAL IMPACT ASSESSMENT
OTHER THEMATIC MAPS
ENVIRONMENTAL IMPACT ANALYSES
REGIONAL PLAN. APPLICATIONS
FUNCTIONS
PRODUCTS
APPLICATION TO REGIONAL PROBLEM-SOLVING

Figure 1

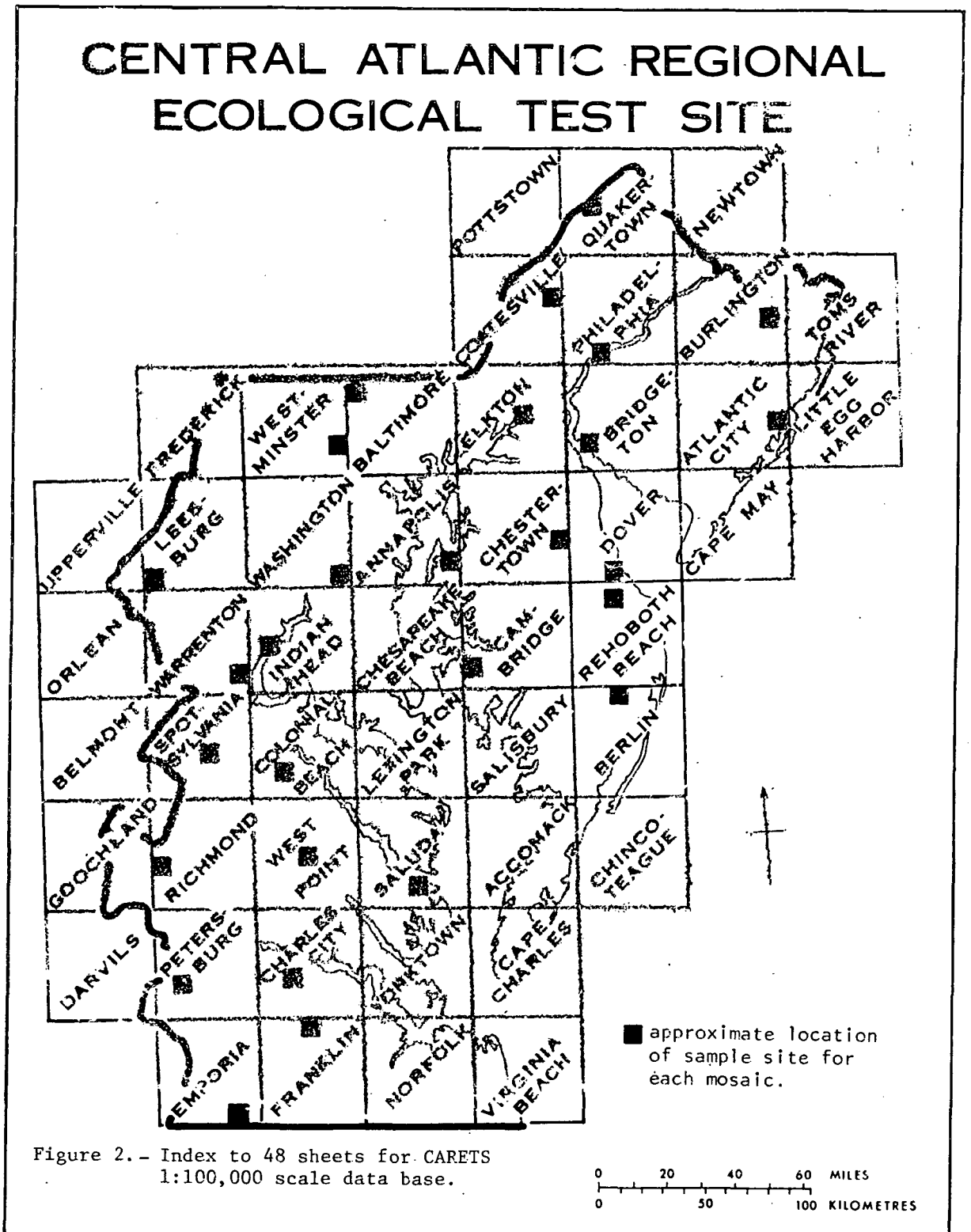
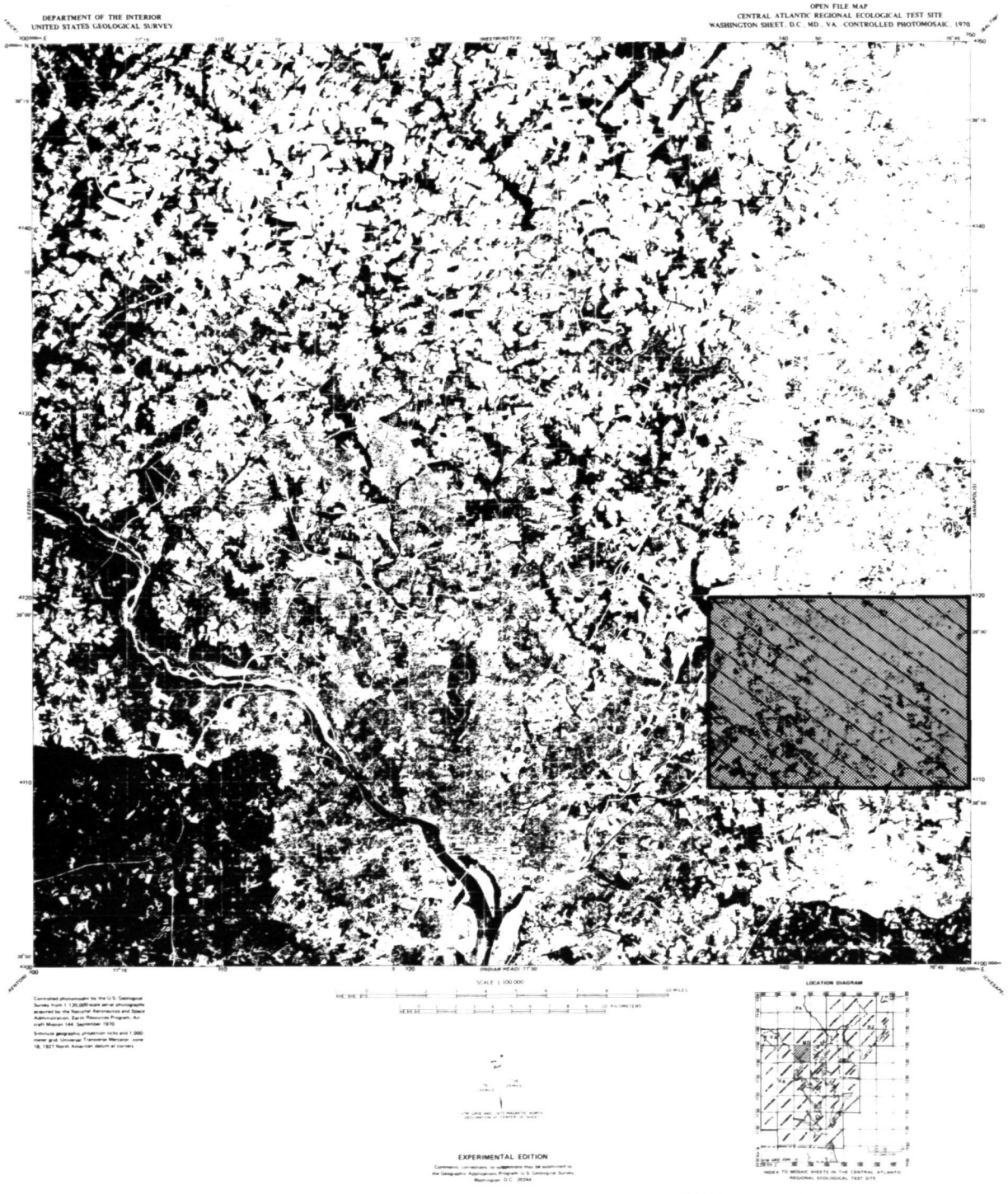
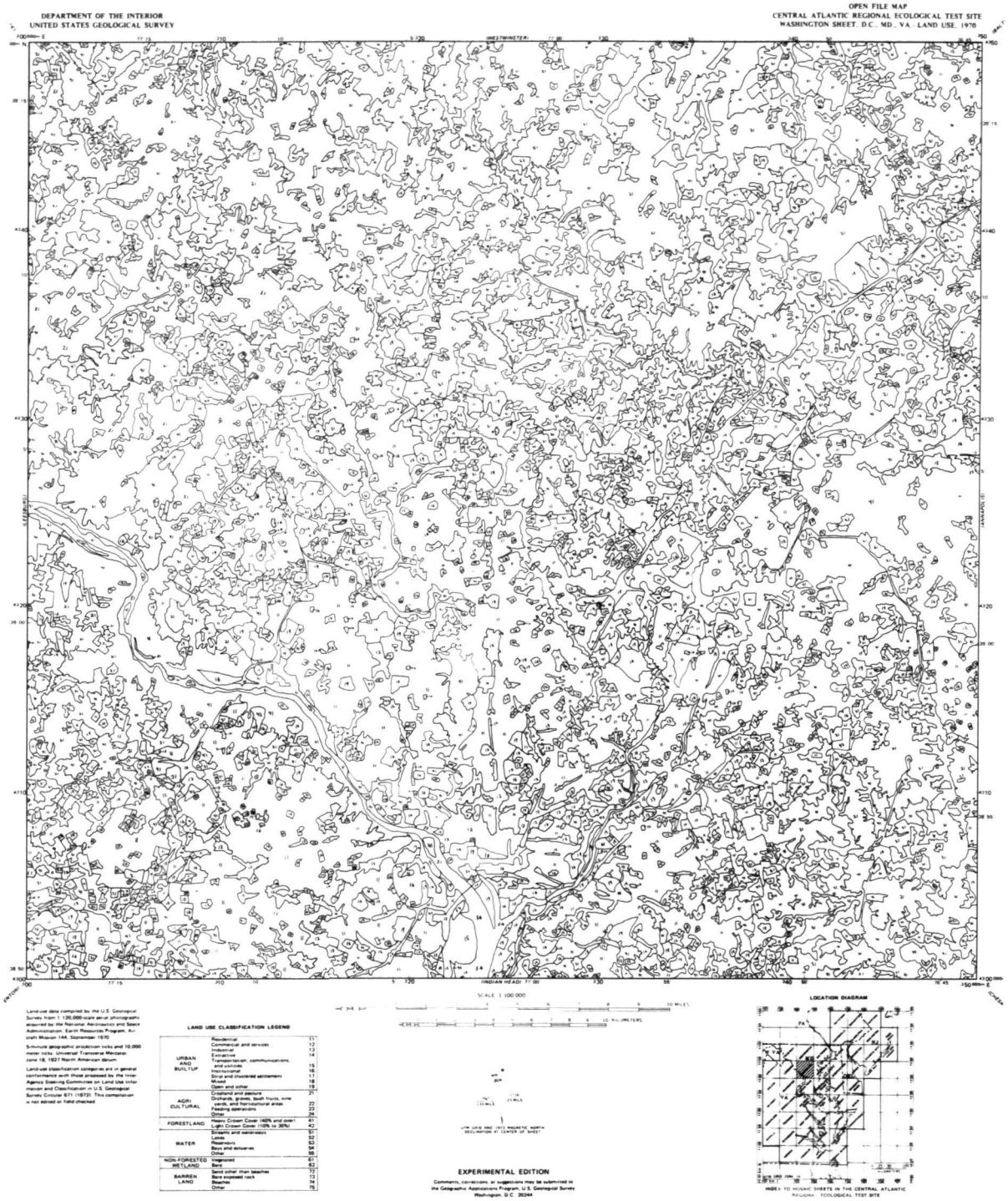


Figure 2.- Index to 48 sheets for CARETS 1:100,000 scale data base.



CONTROLLED PHOTOMOSAIC, 1970, OF THE WASHINGTON SHEET, D.C., MD., VA.
1973

Figure 3. - Reduction of specimen sheet of controlled photomosaic of one of the 48 CARETS sheets. Original sheet 50 x 50 cm at scale 1:100,000. Area outlined is location of detailed coverage in figures 12 through 21.



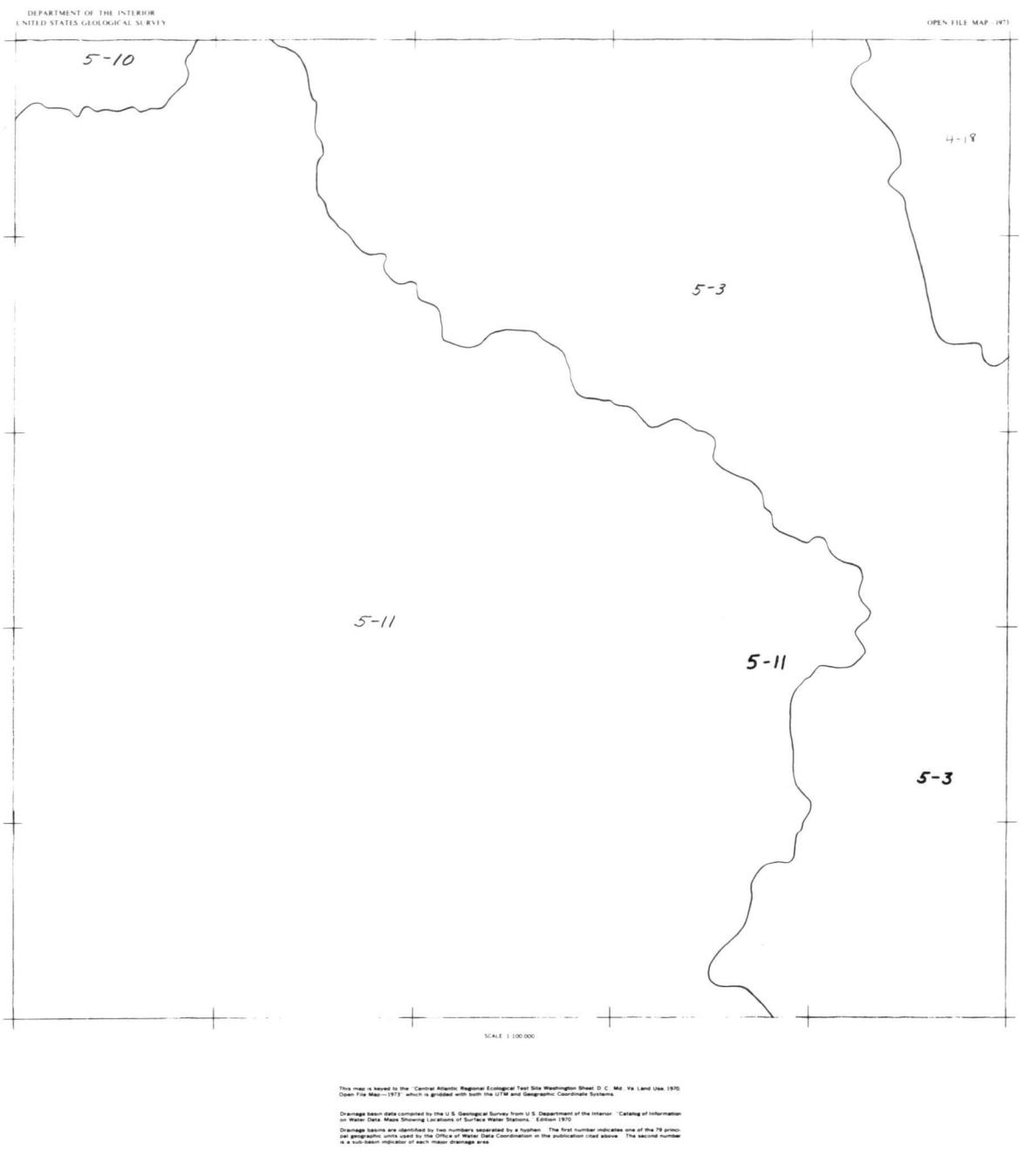
LAND USE MAP IN 1970 OF THE WASHINGTON SHEET, D.C., MD., VA.
1973

Figure 4. - Reduction of specimen sheet of land use map of one of the 48 CARETS sheets. Prepared as overlay to photomosaic (Figure 3).



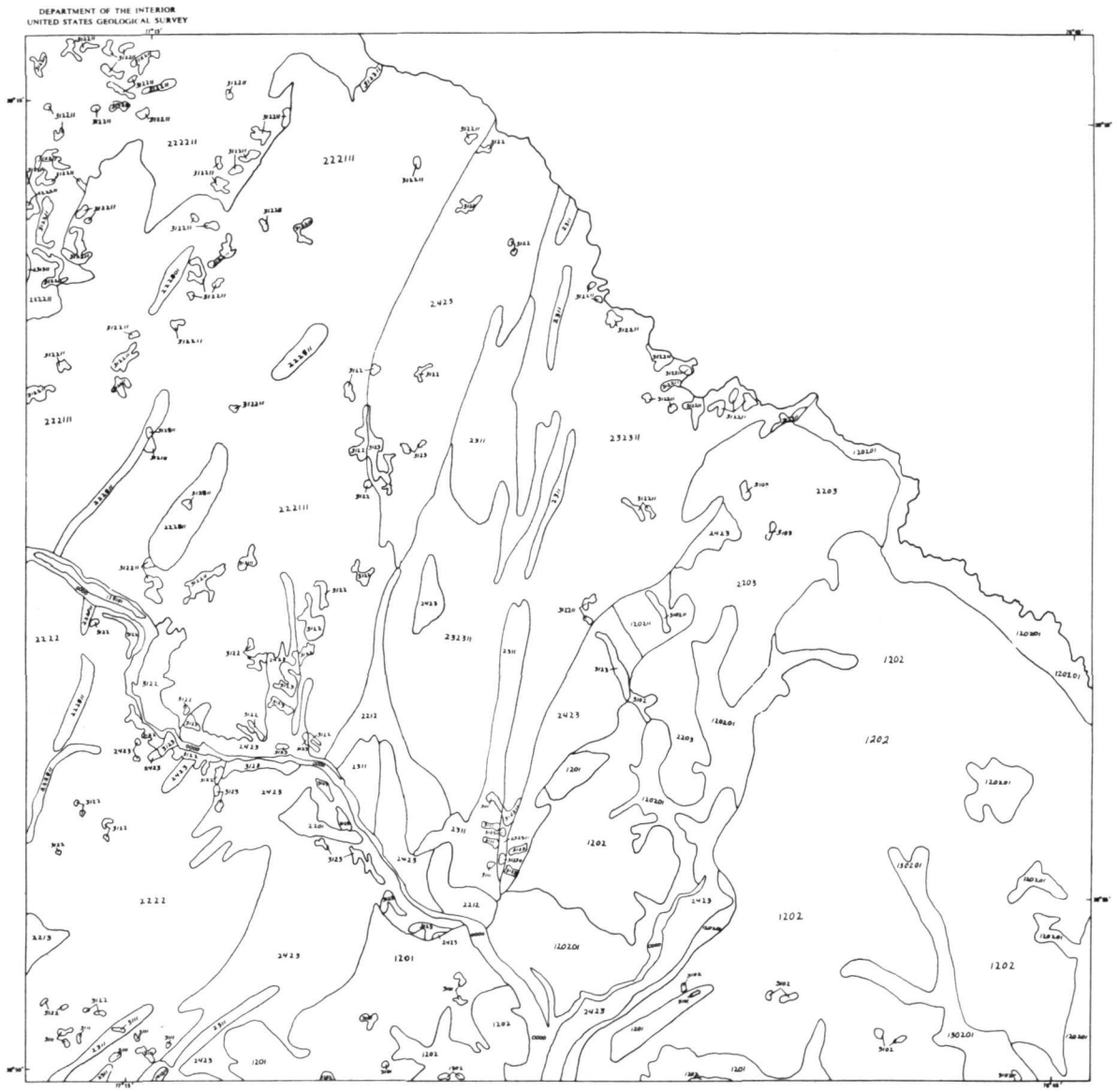
LAND USE CHANGE MAP, 1970–72, WASHINGTON SHEET, D. C., MD., VA.
1973

Figure 5. - Reduction of specimen sheet of land use change map. Prepared as overlay to photomosaic (figure 3).



DRAINAGE BASIN MAP, 1970, WASHINGTON SHEET, D. C., MD., VA.
1973

Figure 6. - Reduction of specimen sheet of drainage basin map. Prepared as overlay to photomosaic (figure 3).



LANDFORMS AND SURFACE MATERIALS MAP, WASHINGTON SHEET, D.C., MD., VA.

Reduced from 1:100,000 scale

Figure 7.- Reduction of specimen sheet of landforms and surface materials map, Washington, D.C., Md., Va. Sheet. Prepared as overlay to photomosaic (figure 3). Key to numbered categories is presented in table II.

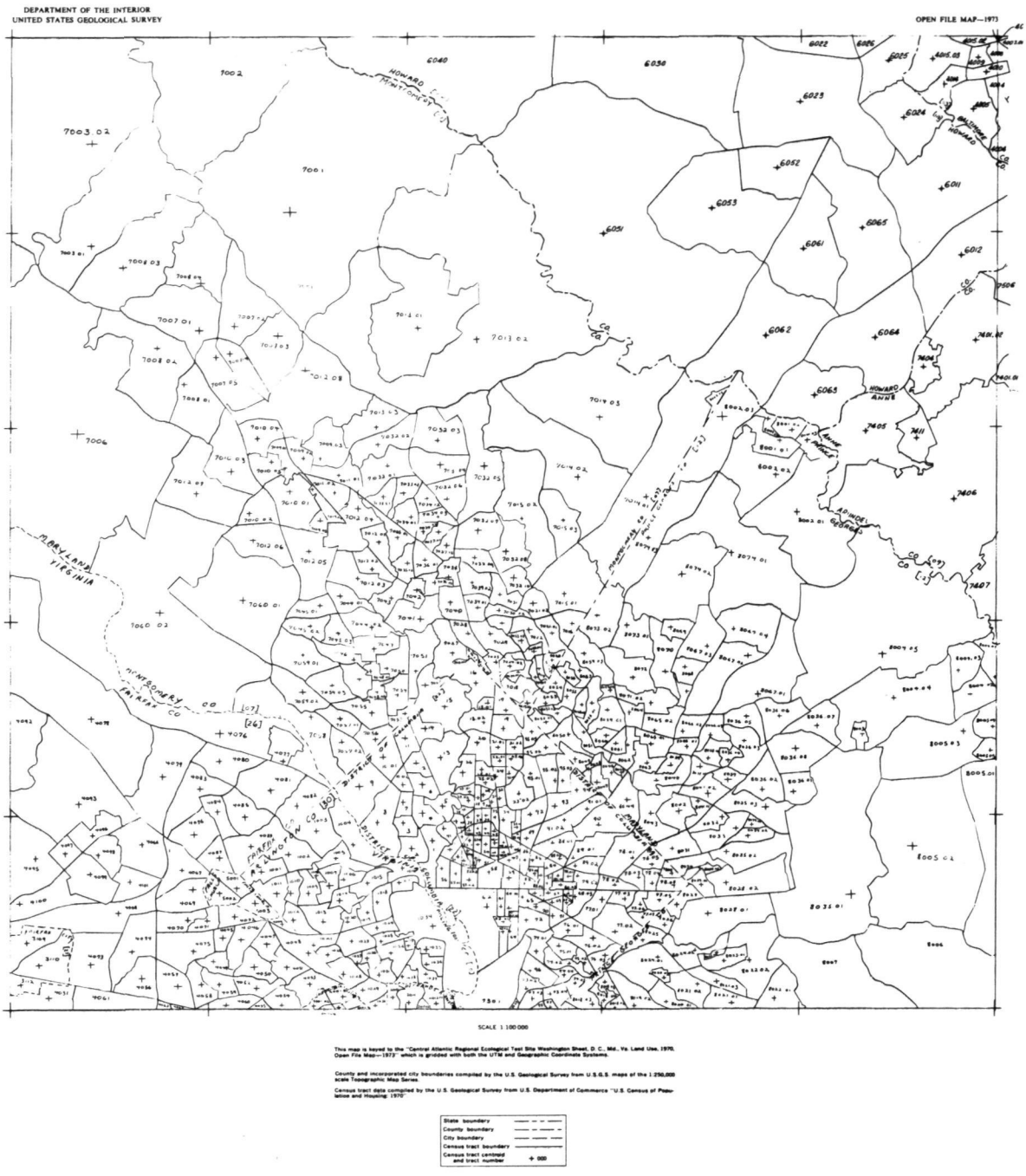
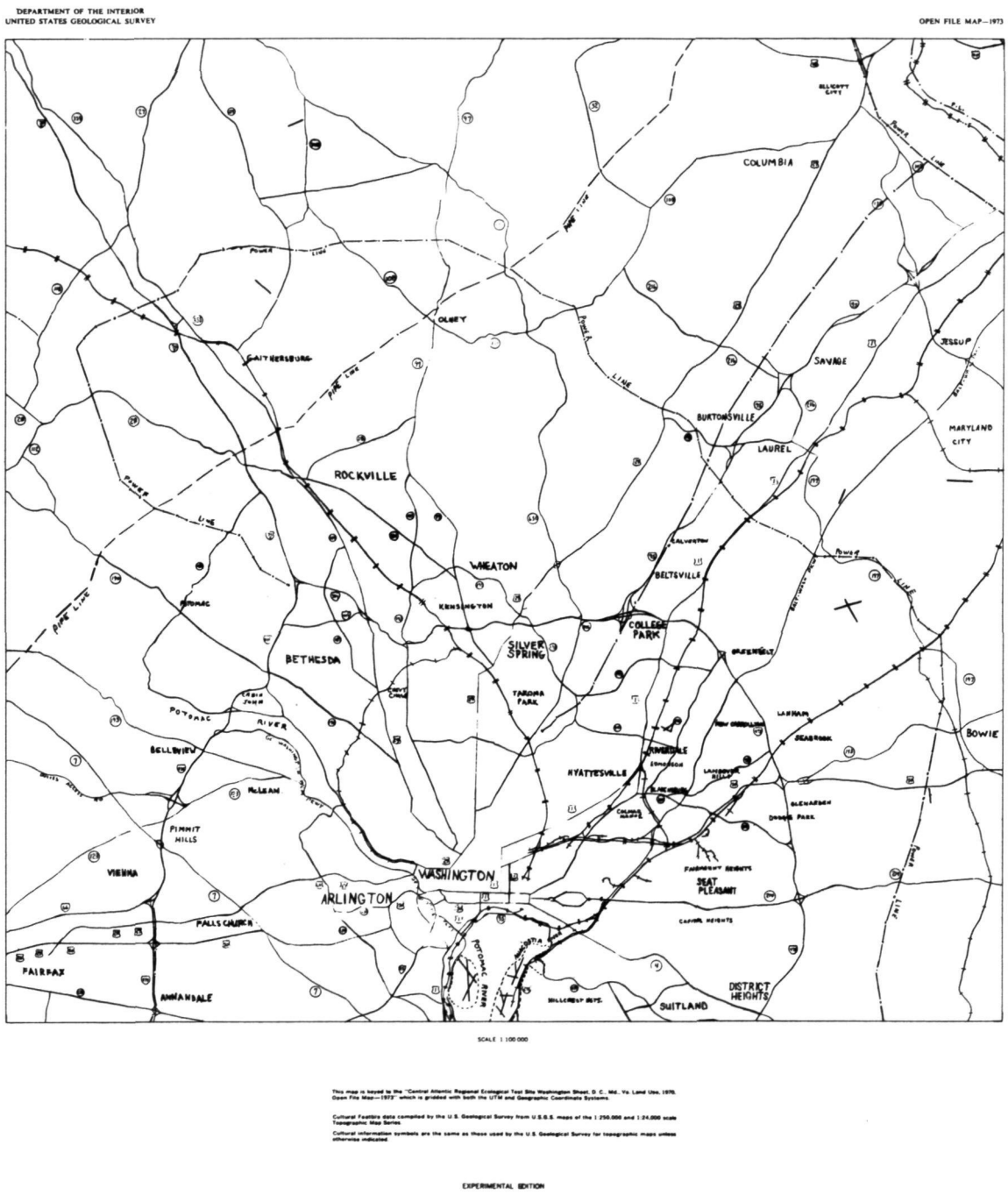


Figure 8.- Reduction of specimen sheet of county boundary and census tract map. Prepared as overlay to photomosaic (figure 3).



This map is keyed to the "Central Atlantic Regional Ecological Test Site Washington Sheet, D. C., Md., Va. Land Use, 1970, Open File Map—1973" which is gridded with both the UTM and Geographic Coordinate Systems.

Cultural Features data compiled by the U.S. Geological Survey from U.S.G.S. maps of the 1:250,000 and 1:24,000 scale Topographic Map Series.

Cultural information symbols are the same as those used by the U.S. Geological Survey for topographic maps unless otherwise indicated

CULTURAL FEATURES MAP, 1970, WASHINGTON SHEET, D. C., MD., VA.
1973

Figure 9.– Reduction of specimen sheet of cultural features map. Prepared as overlay to photomosaic (figure 3).

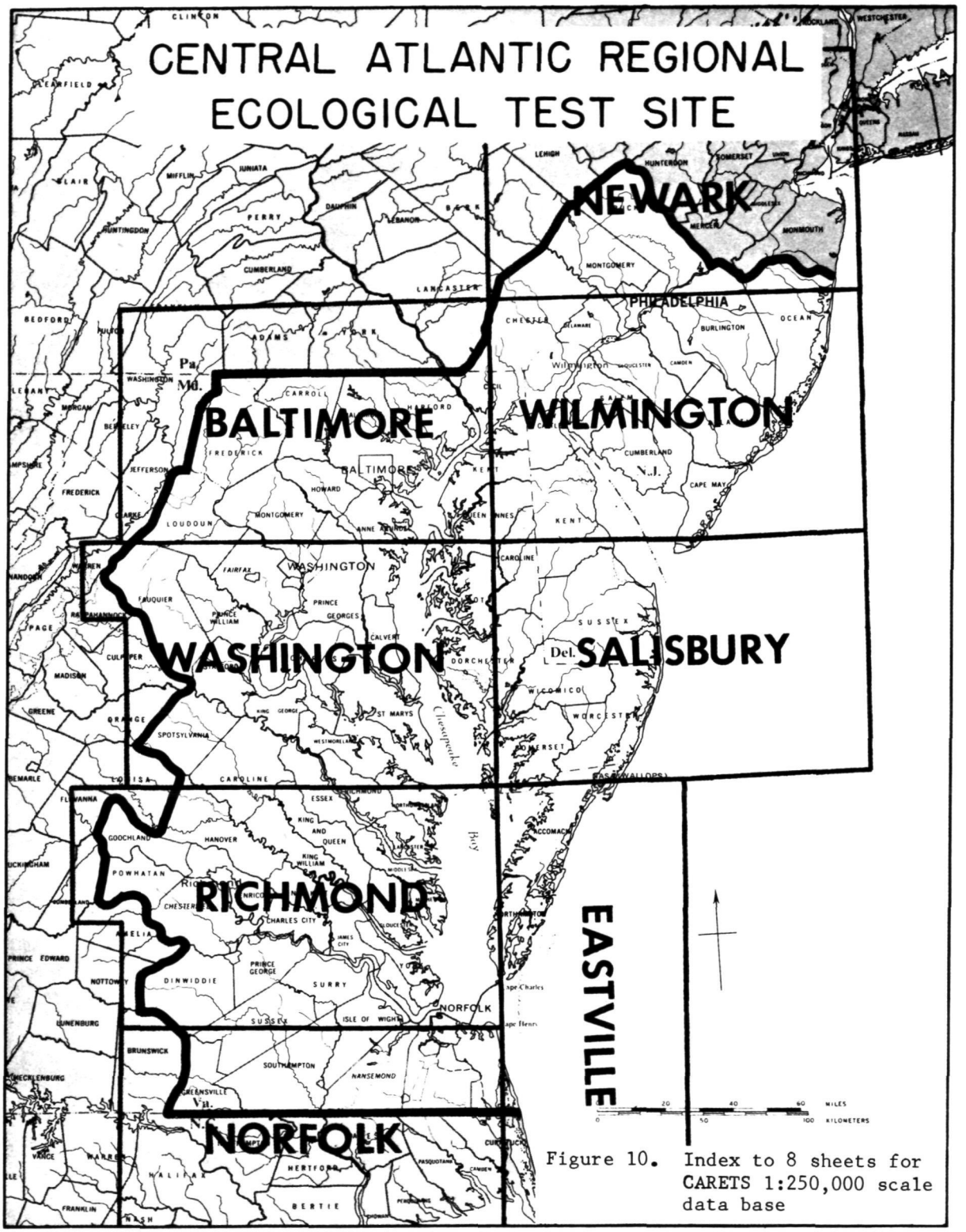


Figure 10. Index to 8 sheets for CARETS 1:250,000 scale data base

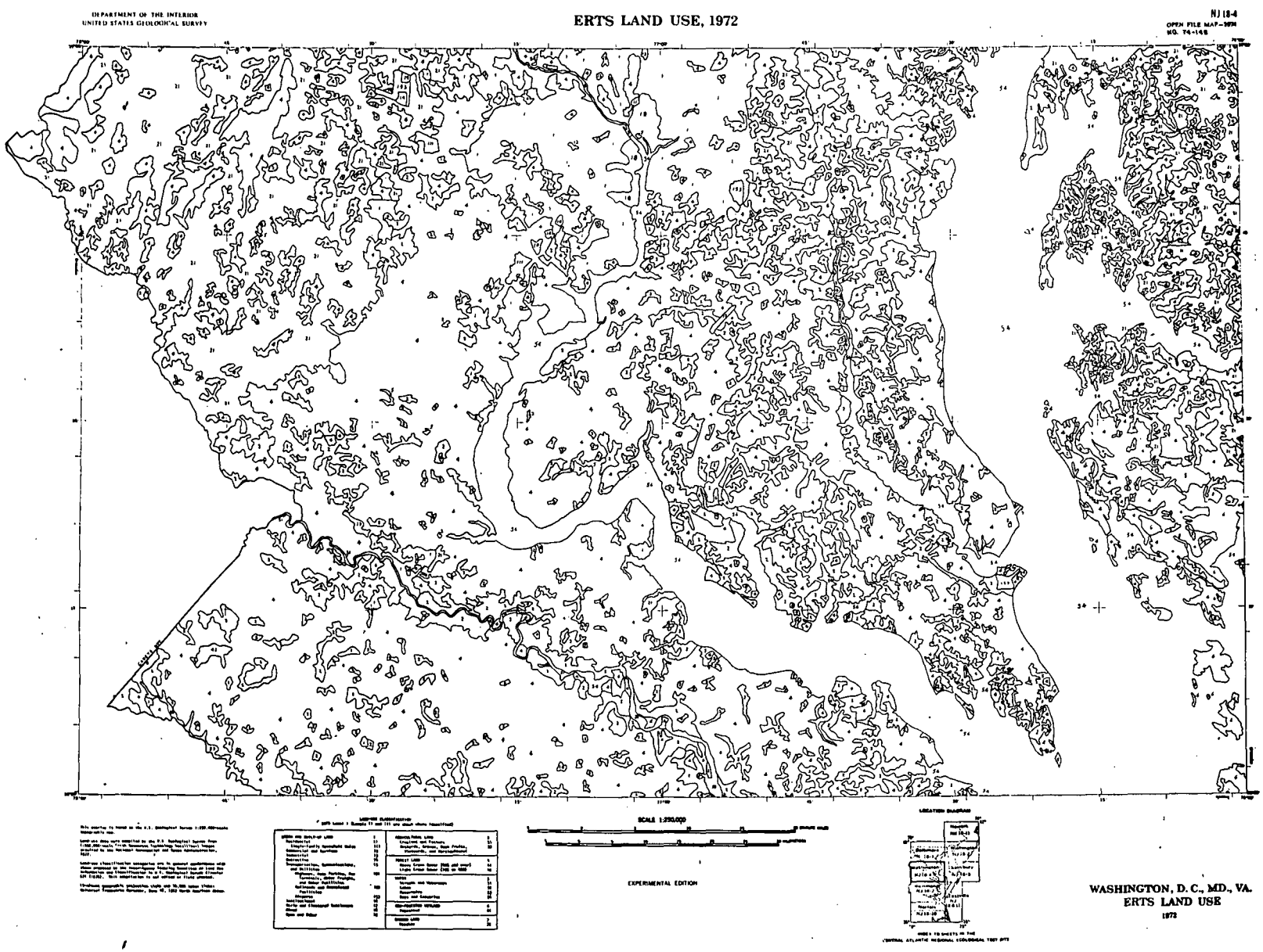


Figure 11.— Reduction of specimen sheet of ERTS-derived land use map. Original at 1:250,000 scale.



Figure 12. - Full-scale (1:100,000) detail of part of photomosaic sheet showing Bowie, Md. (area outlined on figure 3). Grid cells 1 km on a side.

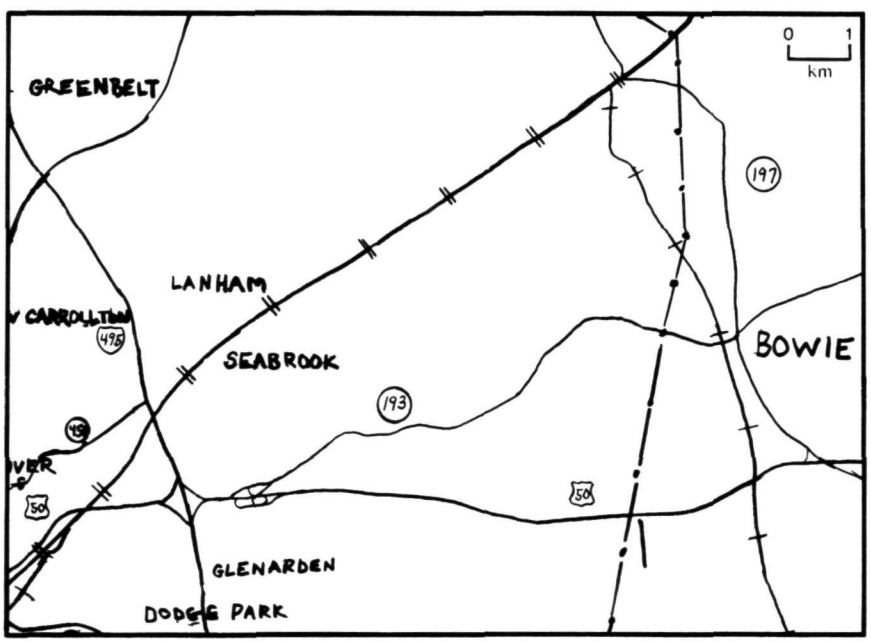


Figure 13. - Full-scale (1:100,000) detail of part of cultural features map, Bowie, Md. (area outlined on figure 3).

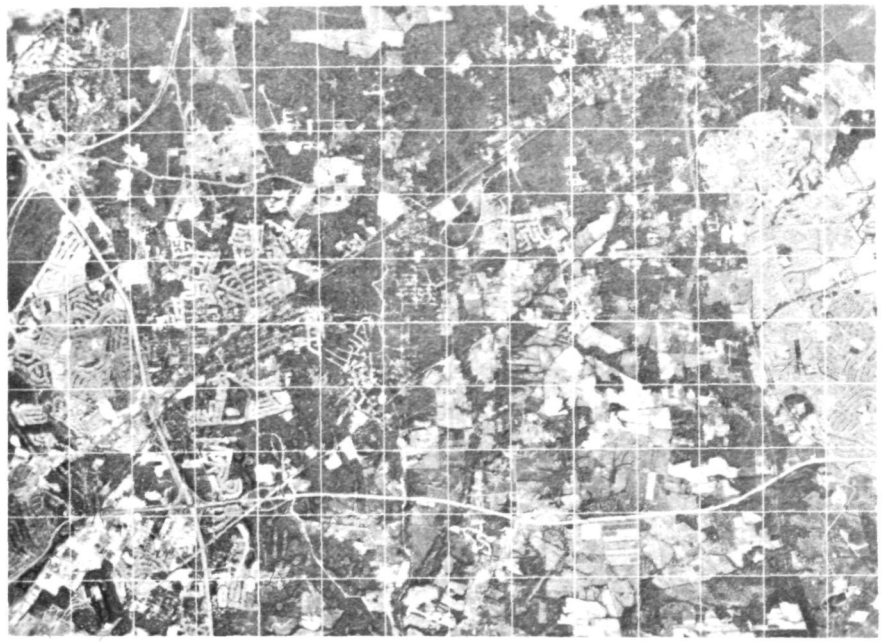


Figure 14. Detail of high-altitude aircraft photo, NASA Mission 144, October 1970, Bowie, Md. (area outlined on figure 3).

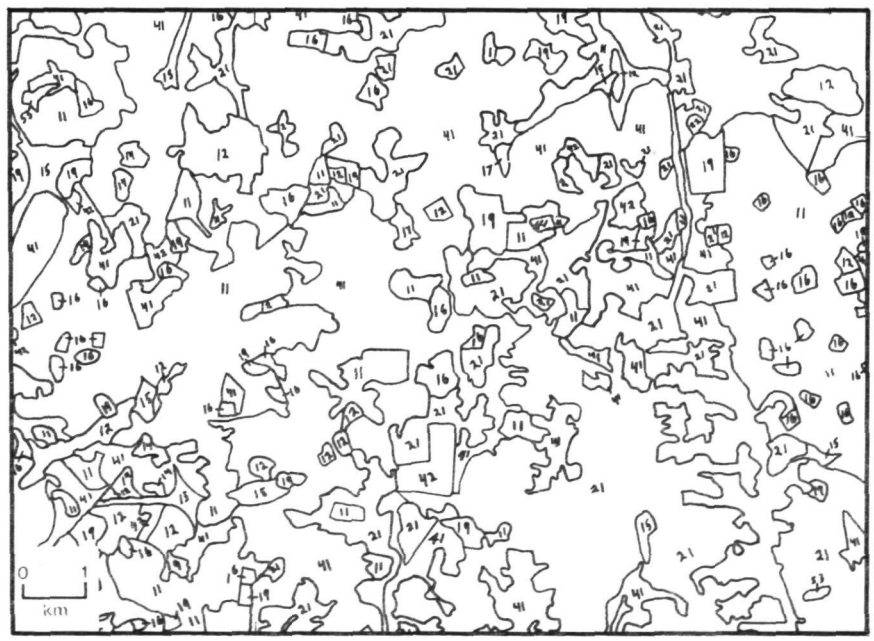


Figure 15. Full-scale (1:100,000) detail of part of land use map, Bowie, Md. (area outlined on figure 3). Key to land use classification categories in table I.

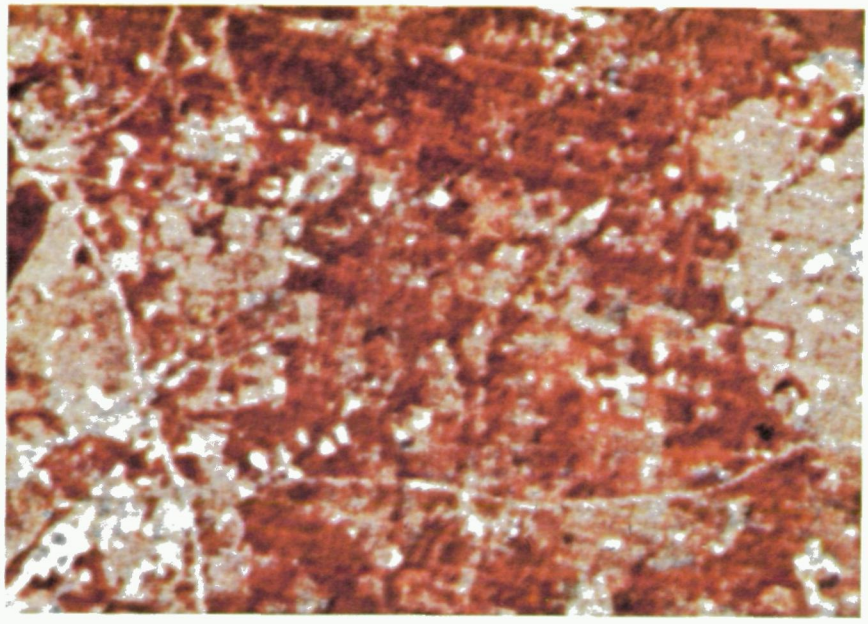


Figure 16. Detail of LANDSAT image E1080-15192, Oct. 11, 1972, color composite of bands 4, 5, and 7, Bowie, Md. (area outlined on figure 3).

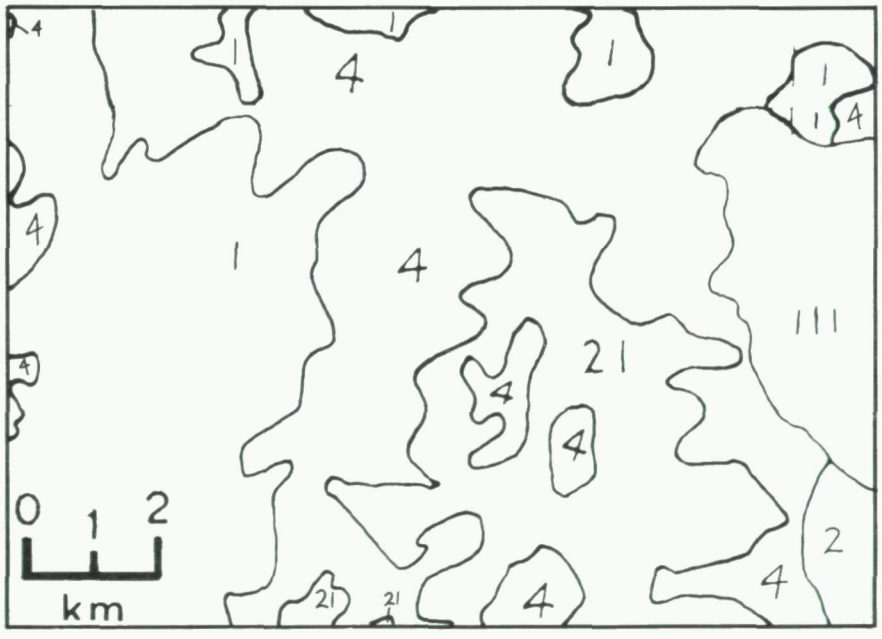


Figure 17. Detail of land use map derived from LANDSAT imagery, enlarged to 1:100,000 from original scale of 1:250,000, Bowie, Md. (area outlined on figure 3). Category iii = single-family residential; 1 = urban and built up; 21 = cropland and pasture; 4 = forest.



Figure 18. Detail of Skylab 3 S190B photo, August 5, 1973, Bowie, Md. (area outlined on figure 3).

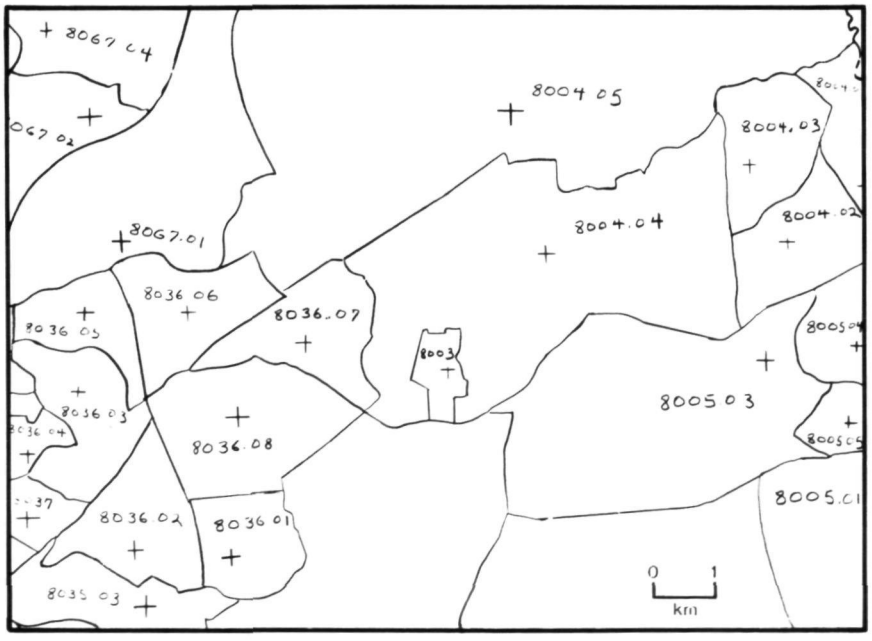


Figure 19. Full-scale (1:100,000) detail of part of census tract and county boundary map, Bowie, Md. (area outlined on figure 3).

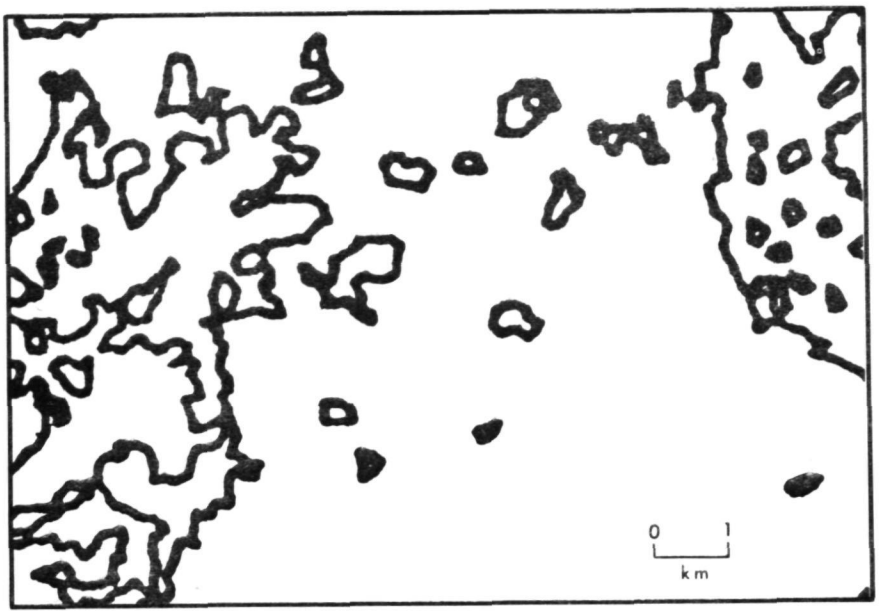


Figure 20. Experimental printout from digitized land use map, Canada Geographic Information System, computer graphics terminal. Callout of urban residential (11) category only, Bowie, Md. (area outlined in figure 3).

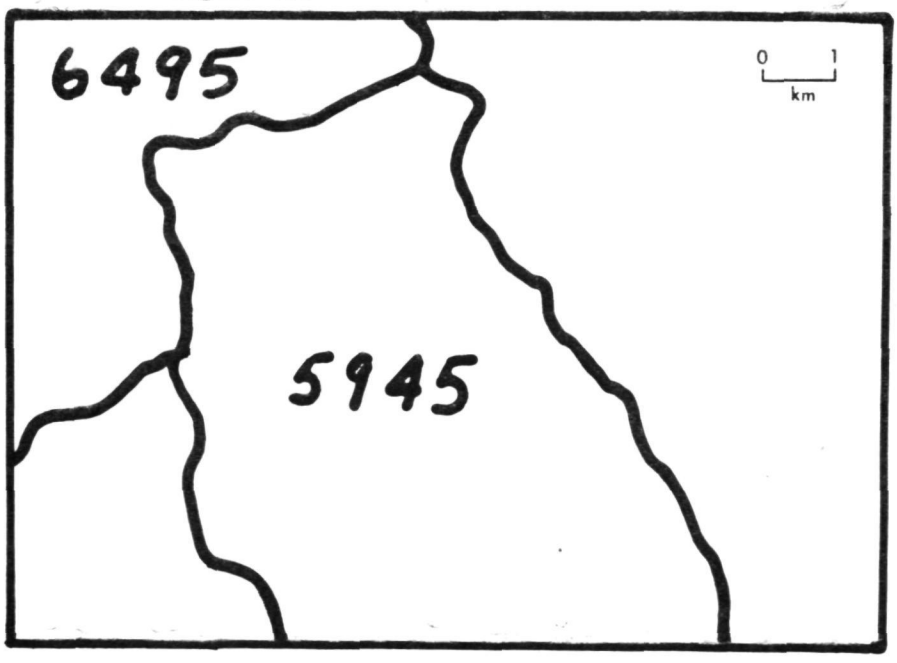
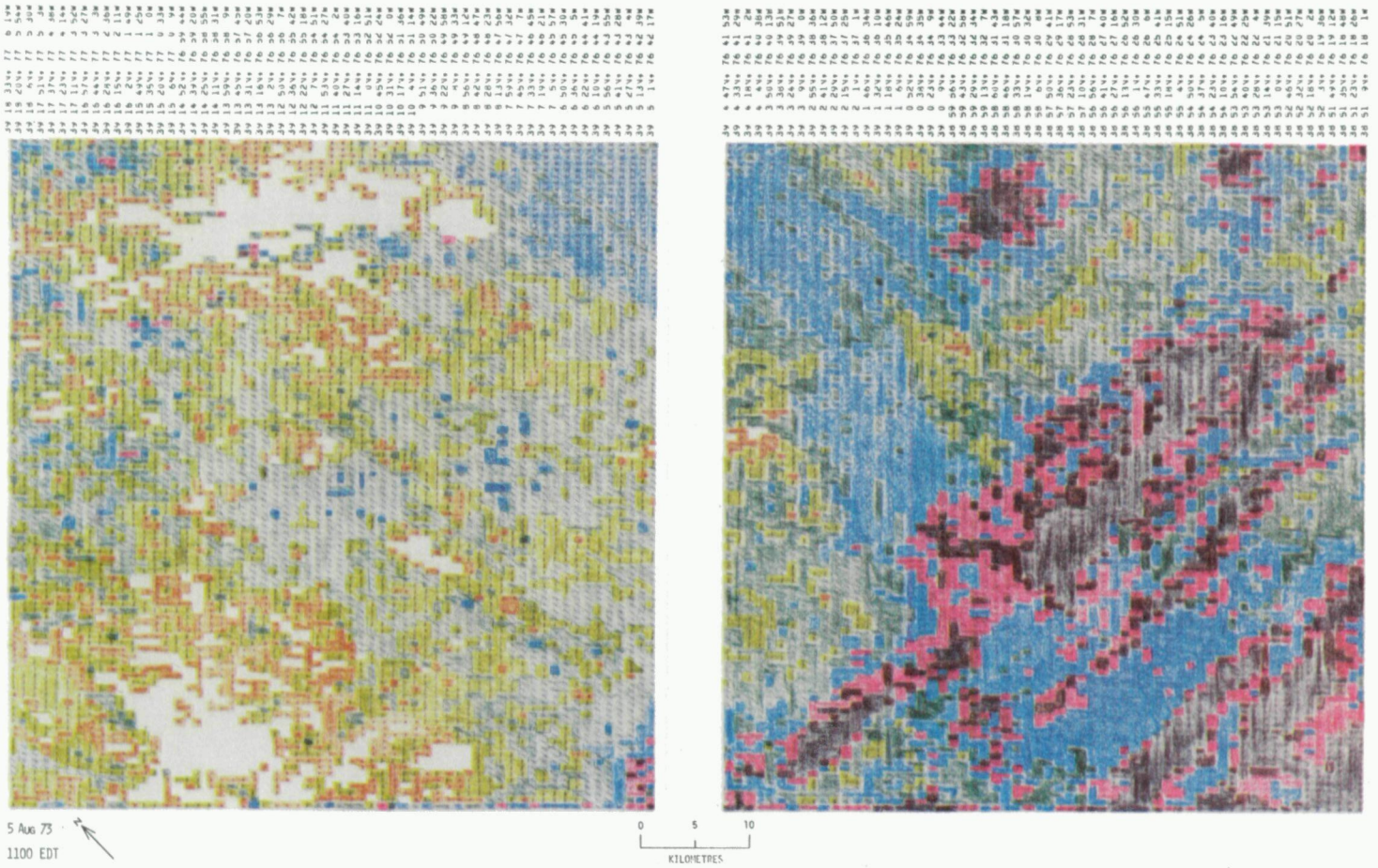


Figure 21. Location of small drainage basins, used in study of the effects of land use on stream runoff characteristics, Bowie, Md. (area outlined on figure 3). Numerical designations used by USGS Water Resources Division.



LEGEND

white	> 36.1°C.
orange	= 33.6-35.6°C.
light green	= 31.1-33.1°C.
dark green	= 28.5-30.6°C.
blue	= 25.9-28.0°C.
purple	= 23.1-25.3°C.
brown	= 20.3-22.6°C.
gray	< 20.3°C.

Figure 22. Hand-colored printout of Skylab S192 thermal data, channel 13, smoothed with 10 pixel by 10 pixel block filter, and calibrated to surface radiometric temperature

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REMOTE SENSING IMPACT ON CORRIDOR SELECTION AND PLACEMENT

L-15

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ABSTRACT

In recent years, the National Environmental Protection Act (NEPA) legislation has required and will require that major developments such as pipeline, powerline, and highway corridors be done at low environmental cost (impact). The anticipated Land Use Policy and Planning Assistance Act (Jackson-Udall Bill) will also probably lead to the requirement that such development be done in a manner consistent with existing land use development plans. In the case of NEPA, environmental impact statements are required for major developments utilizing federal funds. Many states have similar environmental laws with environmental impact statements for other developments.

These legal developments have put additional pressure on planners to locate corridors using objective and defensible procedures and to consider environmental, social and economic impacts as well as construction costs. Computer-aided corridor selection techniques, utilizing digitized data bases of socio-economic, census, and cadastral data, have been developed for highway corridor routing (ref. 1). At ERIM, under sponsorship of the NASA Office of University Affairs Code Y program, we have generated land resource data from various remote sensing data sources, and have, in cooperation with Richard Esch of the Michigan Department of State Highways and Transportation, successfully merged the land resource data generated from LANDSAT-1 with the ancillary data files of Esch's corridor selection model, and designed proto-type highway corridors using the combined data set.

From our point of view, land resource data derived from various remote sensing data, (LANDSAT, aircraft MSS, or photography) when merged with ancillary data and used as input to digital computer corridor location algorithms, represents a powerful and important use of remote-sensing-derived information for operational planning needs. We feel that methodologies of this type will become increasingly important in the future.

In this paper we discuss the types of remote-sensing-derived information we feel are useful for highway corridor location, special considerations in geometric correction of remote sensing data to facilitate merging it with ancillary data files, and special interface requirements. Hopefully our experience with this case will be of help to others contemplating similar activities.

1. INTRODUCTION

Over the past six years, citizen awareness of environmental issues has increased markedly and has resulted in a number of pieces of federal and state legislation (e.g., National Environmental Protection Act of 1970) which require projects developed with public funds to be preceded with environmental impact statements stating the expected impacts of proposed developments and showing that the project has been designed to minimize environmental impact. At the same time the Federal Highway Administration of the Department of Transportation has required all states to develop "action plans" identifying the planning processes used for highway projects which use federal funds.

All these developments have made it imperative that highway and other corridor routes (e.g., pipelines and powerlines) be selected by objective and defensible procedures. Highway planners are turning to new technology such as computer data bases with associated corridor routing algorithms to provide more objective corridor routing.

Michigan has advanced highway corridor routing methodology and has been examining the potential of various remote sensing sources to provide up-to-date land cover information to supplement its computerized file of census and socio-economic data. The Environmental Research Institute of Michigan (ERIM), under funding from the NASA Office of University Affairs (Grant NGR-23-005-552, technical monitor Mr. Joseph Vitale) has cooperated with the Statewide Studies Unit (SSU) of the Michigan Department of State Highways (MDSH) to explore the uses of LANDSAT and RB-57 high-altitude color infrared (CIR) photography for obtaining current land cover information. The LANDSAT efforts are the subject of this paper.

While the discussion of the use of LANDSAT data and the case study presented here focus on the highway planning process, we believe that similar procedures could be used for other corridor routing tasks. LANDSAT and other remote sensing data, when properly processed to yield appropriate information, will have impact on those tasks as well.

2. HIGHWAY PLANNING IN MICHIGAN

Highway planning in Michigan occurs in three distinct phases. The first phase is a "reconnaissance study" to determine the need for a new highway link and the areas the link is to serve. Alternative corridors are also generated. The second phase is a detailed examination of each alternative corridor and the selection of a corridor. The third phase is a detailed engineering study of the placement of the road within the selected corridor.

Remote sensing technology can impact all three stages of highway planning in Michigan, and it does. For reconnaissance studies, the subject of more detailed discussion in the next section, general land cover information (of a degree of complexity of Level I the U.S.G.S. Circular 671 - although not precisely those classes) is useful, along with substantial information regarding traffic volumes, accident rates, population, and services availability (e.g., hospitals or schools). For corridor selection from various equal construction-plus-environmental cost alternatives generated by the reconnaissance study, more detailed land cover information (about Level II) is required. In pilot studies (ref. 2) this information has been obtained by photointerpretation of RB-57 CIR data. No doubt this information could be obtained by computer processing of data from satellites whose sensors are more optimized for land cover sensing than the current LANDSAT-MSS, e.g., the Thematic Mapper.

In the third level of planning, the MDSH currently uses color photography collected over the corridor of interest both as an information source for more detailed land cover information (about Level III) and as a data base.

In the next section, we discuss in detail a case study of the use of land cover information derived from LANDSAT data to the reconnaissance planning of a hypothetical highway corridor. The work reported was a cooperative project between ERIM and Mr. Richard Esch of MDSH-SSU.

3. A HIGHWAY CORRIDOR ROUTING CASE STUDY

Richard Esch, of MDSH-SSU has developed a highly versatile statewide transportation model shown in figure 1 (see also ref. 1). While figure 1 shows all model capabilities, and is therefore complex, there are three generic types of modules which make up the overall model. First, there are a set of files - Statewide Network File, Statewide Socio-Econ File, and Statewide Facilities File - containing basic information. In the middle of figure 1 are a set of models which use data from the files to make calculations. At the bottom is a graphics display battery for displaying model calculations. Figures 2, 3, and 4 show some of the information present in the basic data files.

Corridor location has been done with only the data from the files shown, although for optimum results, land resource data should be used in conjunction with the existing data files. The general situation is illustrated in figure 5. We hope to be able to create a natural characteristics data file to supplement the existing data files. Remote sensing will be able to supply many but not all of the natural characteristics data, and possibly some of the cultural characteristics required for effective corridor location.

3.1 THE CASE STUDY

As a demonstration of the ability of the existing model to use land cover information extracted from ERTS-CCT's by computer processing, a case study was performed. ERIM acquired and processed data from the Munising, Michigan area in the north center of the Upper Peninsula. An eight category recognition tape was prepared, with the classes shown in Table I. The tape was further processed by Richard Esch. Since the model operates on a cell basis, the cells are larger than the 1.1 acre LANDSAT resolution element, the first step was an aggregation of the recognition tape data. Data were aggregated over 8 x 16 arrays of LANDSAT resolution elements, yielding a grid size of 140.8 acres. The percentage of each land cover class was computed for each 110 acre model grid cell. Example maps (representing an area of 5 x 9 mi) showing the percentage of water and urban are presented in figures 6 and 7. The large water area at the top of figure 6 is Lake Superior, while smaller aggregations of water down the left hand side of figure 6 are other lakes. In figure 7, Munising is at the upper right center. Using the digital tape recognition file, Richard Esch first preapred a location determinant composite file from the land cover data. This location determinant shown in figure 8 was, in this case, a composite of urban and water, although it could have been created from a linear sum of all classes. The weight for water was -10 and that for urban +10, as shown in figure 9.

Figure 9 also shows the relative weights given to the location determinants (in this case only LANDSAT-derived land cover information) and the link distance (related to cost of highway construction) in selecting the corridor. In practice, the model would be exercised with different sets of relative weights to generate several alternative corridors. Land cover as well as highway construction costs were used in this example, and thus the location of corridors can be done to minimize overall cost of construction plus environmental cost.

For this case study, the optimal corridor from the start, at the top, to the end, at the bottom is shown by the line in Figure 10. Notice that near the top the line passes through cells with relatively little water, rather than through cells which are predominantly water. This occurs because of the (assumed) high environmental cost of building a highway over water. (The construction cost would obviously be large.)

3.2 REMOTE SENSING SYSTEM CONSIDERATIONS

There are at least three remote sensing system considerations important when preparing land cover information to be used in models such as the MDSH-SSU corridor selection model. The three most important considerations are the type of information required and its accuracy, the format of the information supplied, and the geometric quality of the supplied information.

We have previously discussed the idea that reconnaissance corridor routing can be done with fairly coarse land cover information, as shown in figure 5. The accuracy requirements for this information have not yet been precisely defined, but the current machine processing capabilities of LANDSAT data are such that information derived by this means would probably be very useful for initial tests of corridor selection using land cover information.

Since most models are implemented on digital computers, having a digital format input of land cover information is a necessity. Machine processed LANDSAT data is inherently digital format information, and thus has advantages over photointerpreted products which must be digitized before they can be used by the model. Accuracy checking the machine processed data is conveniently done with the information in pictorial format. But the availability of digitally controlled ink jet printers such as that sent by Mead Technology Labs or available on ERIM's MIDAS (Multivariate Interactive Digital Analysis System) (ref. 3), make creation of pictorial output from digital tape much easier to do than to digitize pictorial data.

Geometric correction must be performed on the raw LANDSAT data in order to be able to merge the land cover information with other information sources. The accuracy with which this is done depends on the number and sizes of the grid cells in the model and the accuracy with which the information needs to be registered. Some measure of the size of grid cells may be gained from figure 11. This figure shows the old 547 cell system for the State of Michigan. Recently, the model has been expanded to 2300 cells, and there are plans to go to a larger number of cells. All cells are not the same size, as can be seen from the figure. If we assume a 4:1 variation in cell size and 58,000 sq miles for the State of Michigan, then the smallest zone is 6.3 sq miles or about 23 km on a side if the zone is square. Assuming a registration accuracy to $\pm 1\%$ of the width of the zone, the required geometric accuracy is ± 230 m. This is well within the range of LANDSAT capabilities. Of course, the reference grid used in many state studies is not UTM or latitude-longitude, but a state plane coordinate system. Michigan is no exception. Fortunately, in Michigan's case there is only one grid system, which makes the registration job somewhat easier.

4.0 CONCLUSIONS

Ability of current LANDSAT data processing technology to provide land cover information to upgrade satewide reconnaissance corridor routing has MDSH very interested. Continued development of this capability will require further inflow of federal dollars, because new technology research is low on Michigan's State Budget priority list as it is with nearly every state.

We feel that our case study has generated interest and holds promise for upgrading highway and other corridor planning. We look forward to taking the next step.

REFERENCES

1. R. E. Esch, "Michigan's Statewide Traffic Forecasting Model", Michigan Department of State Highways, September 1972.

2. I.J. Sattinger, et al., "Remote sensing in Michigan for land resources management: Annual Report, 1 June 1972 to 1 June 1973" Report 193400-2-F, Environmental Research Institute of Michigan, Ann Arbor, Michigan, July 1973.

3. F.J. Kriegler, et al., "MIDAS, Prototype Multivariate Interactive Digital Analysis System - Phase I", Report 195800-25-F, NASA CR-132463, Environmental Research Institute of Michigan, Ann Arbor, Michigan, August 1974.

TABLE I

CLASSES OF THE EIGHT-CATEGORY
RECOGNITION TAPE

Urban
Open
Hardwood Forest
Water
Conifer Forest - Jack Pine
Marsh
Conifer Forest - White Pine
Managed Hardwood Forest

STATEWIDE MODELING SYSTEM COMPONENTS

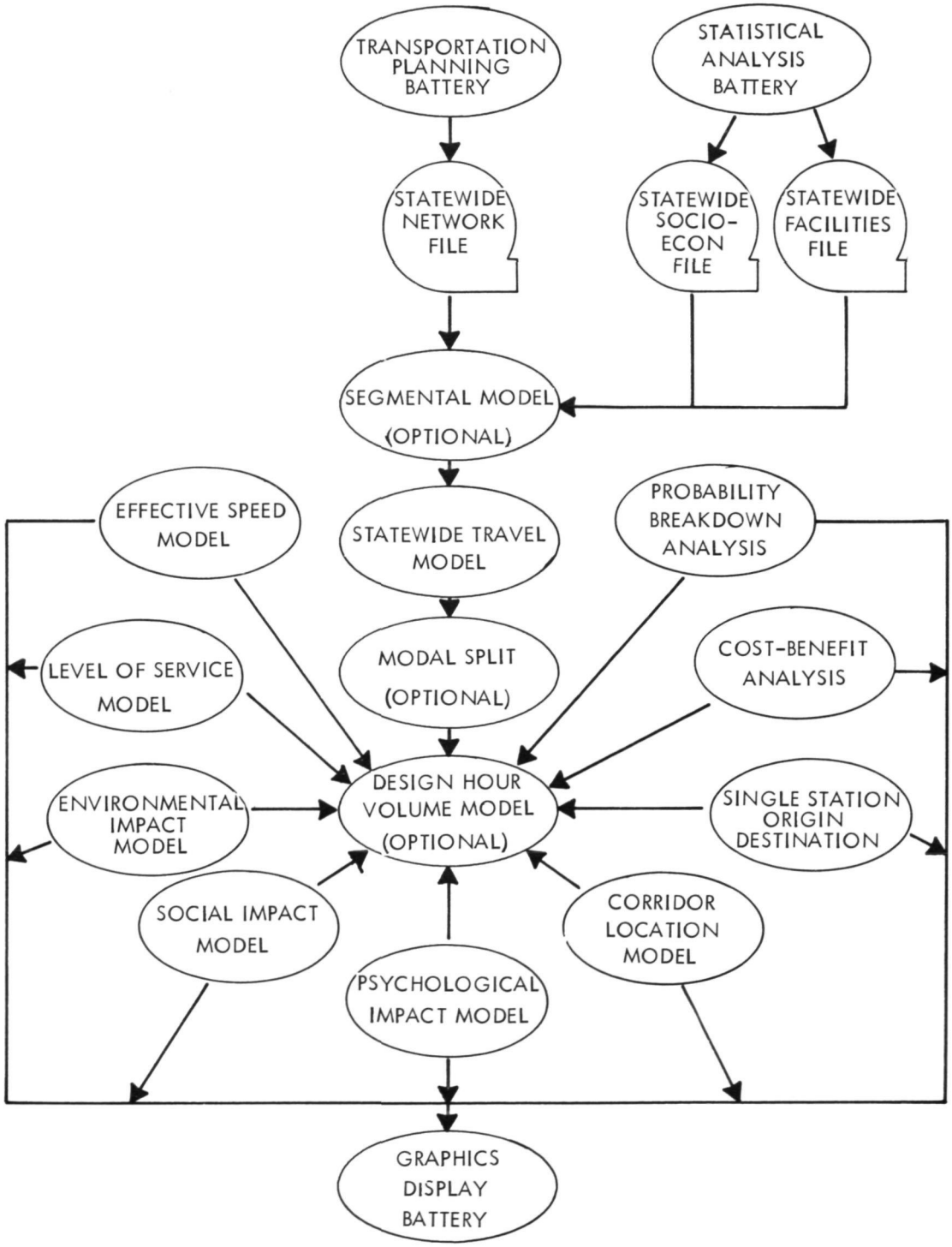


Figure 9

STATEWIDE SOCIO-ECONOMIC DATA FILE *

GENERAL CHARACTERISTICS OF POPULATION

SCHOOL ENROLLMENT BY TYPE OF SCHOOL
YEARS OF SCHOOL COMPLETED
CITIZENSHIP BY AGE

INCOME CHARACTERISTICS OF POPULATION

FAMILY INCOME
INCOME BY OCCUPATION AND SEX
RATIO OF FAMILY INCOME TO POVERTY LEVEL

LABOR FORCE CHARACTERISTICS OF POPULATION

EMPLOYMENT BY AGE
EMPLOYMENT BY OCCUPATION AND SEX
EMPLOYMENT BY INDUSTRY AND SEX

SOCIAL CHARACTERISTICS OF POPULATION

AGE BY SEX
TYPE OF FAMILY
MARITAL STATUS

AREA CHARACTERISTICS

LAKE FRONTAGE
ASSESSED VALUATION
WATER AREA

*THOSE ITEMS LISTED HERE ARE SAMPLES TAKEN FROM THE COMPLETE FILE WHICH CONTAINS OVER 700 ITEMS.

FIGURE 2

STATEWIDE HIGHWAY NETWORK

LINK FILE

CONTENTS OF EACH HIGHWAY SEGMENT OR LINK

AVERAGE SPEED
DISTANCE
URBAN-RURAL DESIGNATION
TYPE OF ROUTE
TRAFFIC VOLUME CAPACITY
AVERAGE ANNUAL DAILY TRAFFIC VOLUME
COMMERCIAL TRAFFIC VOLUME
DESIGN HOUR VOLUME
ACCIDENT FATAL RATE
ACCIDENT INJURY RATE
ACCIDENT RATE
NUMBER OF LANES
LANE WIDTH
SURFACE CONDITION
RIGHT OF WAY
SIGHT RESTRICTION

FIGURE 3

STATEWIDE FACILITY FILE

HISTORIC SITES
HOSPITALS
AIRPORTS
WHOLESALE TRADE CENTERS
MAJOR PARKS
NON-PUBLIC COLLEGES
PUBLIC COMMUNITY COLLEGES
CITIES OVER 30,000 POPULATION
UNEMPLOYMENT OFFICES
MENTAL HEALTH CENTERS
CERTIFIED INDUSTRIAL PARKS
MICHIGAN'S UNIVERSITIES
SKI AREAS
SNOWMOBILE TRAILS
CBD w/5,000 POPULATION
TRUCK TERMINALS
STATE POLICE POSTS
DAILY NEWSPAPERS
WEEKLY NEWSPAPERS
SEWAGE TREATMENT FACILITIES
TOURIST ATTRACTIONS
BUS TERMINALS
MANUFACTURERS
CAMPSITES

FIGURE 4

CORRIDOR LOCATION VARIABLES

(1) NATURAL CHARACTERISTICS

WATERS - STREAMS, RIVERS, LAKES, ETC.

VEGETATION - BARREN LAND, FORESTS, NATURAL AREAS

TOPOGRAPHY - ORIENTATION, DIRECTION, SLOPE, ELEVATION CHANGE

SOIL CONDITION - SURFACE AND SUBSURFACE SOIL TYPES

(2) CULTURAL CHARACTERISTICS

LAND USE - EXISTING AND PLANNED RESIDENTIAL, COMMERCIAL,

INDUSTRIAL, AGRICULTURAL, RECREATIONAL AREAS

POPULATION DISTRIBUTION - URBAN CENTERS OF VARIOUS SIZES

COMMUNICATION SYSTEM - LOCAL ROADS, ARTERIALS,

FREEWAYS, UTILITY LINES

FIGURE 5

% WATER

94	94	94	94	94	94	94	51	0	0	36	0	0
100	100	100	100	74	98	100	100	26	0	37	0	0
100	100	100	100	79	83	100	100	99	85	3	0	0
100	100	100	100	100	100	100	99	100	100	20	0	0
100	100	100	100	91	84	97	91	100	100	56	0	0
100	98	42	13	1	0	2	86	100	100	84	2	0
100	54	0	0	0	0	0	2	30	90	100	97	41
100	26	0	0	0	0	0	0	0	13	43	31	2
100	38	0	0	0	0	0	0	0	2	0	0	0
59	13	0	0	0	0	0	0	0	0	0	0	0
7	0	0	0	0	0	0	0	0	0	3	0	0
26	25	0	0	0	0	0	0	0	4	19	11	0
98	45	0	0	0	0	0	0	0	0	0	2	0
53	2	0	0	0	0	0	0	0	0	0	0	0
5	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	2	0	0
0	1	0	1	0	0	0	0	0	0	0	0	0
0	0	1	0	0	4	5	0	0	0	0	0	0
0	0	13	0	0	0	0	0	0	3	0	0	3
0	1	32	1	0	0	0	0	0	15	38	2	0
0	26	13	0	0	25	0	0	0	18	38	1	0
0	19	20	0	2	1	0	0	0	0	0	0	0
0	1	48	0	0	0	0	0	9	0	0	0	2
0	0	57	13	0	0	0	0	11	7	0	2	13
0	0	15	73	5	0	0	0	2	0	38	1	0

FIGURE 6

% URBAN AREA

0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	0	0	0	0	0	0	0	0	0	0	0
0	0	2	0	0	0	0	0	0	2	0	0	1
0	0	2	0	0	0	6	5	2	19	23	4	1
0	0	6	7	5	8	12	4	0	2	4	2	5
2	3	2	1	7	0	11	5	0	0	1	0	0
9	1	0	0	1	0	0	1	0	2	3	1	0
0	0	0	0	0	0	1	12	0	3	2	2	0
0	0	0	0	0	0	0	0	2	6	0	1	0
0	0	0	0	0	0	0	2	2	6	6	2	2
0	2	0	0	0	1	5	0	2	9	17	5	2
0	2	0	0	0	3	0	2	9	1	1	5	17
0	7	0	1	0	0	0	2	2	16	19	23	4
5	0	0	0	0	0	3	13	16	13	2	0	8
34	3	1	0	0	0	0	2	9	2	1	1	0
31	21	0	0	1	0	0	0	1	1	0	0	0
18	23	0	0	0	0	0	1	5	2	1	1	0
9	9	0	1	0	2	11	1	0	0	1	2	1
8	2	0	7	0	4	59	35	2	0	0	0	3
6	22	9	9	2	4	12	13	2	0	1	0	1
33	49	26	2	5	2	6	2	0	0	0	0	0

FIGURE 7

LOCATION DETERMINANT--COMPOSITE

-94	-94	-94	-94	-94	-94	-94	-51	0	0	-36	0	0
-100	-100	-100	-100	-74	-98	-100	-100	-26	0	-37	0	0
-100	-100	-100	-100	-79	-83	-100	-100	-99	-85	-3	0	0
-100	-100	-100	-100	-100	-100	-100	-99	-100	-100	-20	0	0
-100	-100	-100	-100	-91	-84	-97	-91	-100	-100	-56	0	0
-100	-98	-42	-13	-1	0	-2	-86	-100	-100	-84	-2	0
-100	-54	2	0	0	0	0	-2	-30	-88	-100	-97	-40
-100	-26	2	0	0	0	6	5	2	6	-20	-27	-2
-100	-38	6	7	5	8	12	4	0	1	4	2	5
-58	-9	2	1	7	0	11	5	0	0	1	0	0
2	1	0	0	1	0	0	1	0	2	0	1	0
-26	-25	0	0	0	0	1	12	0	-1	-16	-9	0
-98	-45	0	0	0	0	0	0	2	6	0	-1	0
-53	-2	0	0	0	0	0	2	2	6	6	2	2
-5	2	0	0	0	1	5	0	2	9	17	5	2
0	2	0	0	0	3	0	2	9	1	-1	5	17
0	6	0	0	0	0	0	2	2	16	19	23	4
5	0	-1	0	0	-4	-2	13	16	13	2	0	8
34	3	-12	0	0	0	0	2	9	-1	1	1	-3
31	20	-32	-1	1	0	0	0	1	-14	-38	-2	0
18	-2	-13	0	0	-25	0	1	5	-16	-37	0	0
9	-10	-20	1	-2	2	11	1	0	0	1	2	1
8	2	-48	7	0	4	59	35	-7	0	0	0	2
6	22	-48	-3	2	4	12	13	-9	-7	1	-2	-12
33	49	11	-71	-1	2	6	2	-2	0	-38	-1	0

FIGURE 8

HIGHWAY LOCATION DYNAMICS

MICHIGAN STATEWIDE STUDIES
PROPOSED HIGHWAY IN MUNISING AREA
LAND DATA FROM ERTS RECOGNITION TAPE

STUDY AREA SIZE 25 CELLS BY 13 CELLS
CELL SIZE 140.8
NUMBER OF LOCATION DETERMINANTS 9

LOCATION DETERMINANT		WEIGHT
1	URBAN AREA	10.0
2	OPEN AREA	0.0
3	HARDWOOD FOREST	0.0
4	WATER	-10.0
5	CONIFER FOREST JACK PINE	0.0
6	MARSH LAND	0.0
7	CONIFER FOREST WHITE PINE	0.0
8	HARDWOOD FOREST MANAGED	0.0
9	NOT CLASSIFIED	0.0

LINK VALUE COMPONENT	WEIGHT
LOCATION DETERMINANTS	10.0
LINK DISTANCE	10.0

ALPHA	0.1
TOLERANCE	0.0

FIGURE 9

OPTIMAL ALTERNATIVE 1

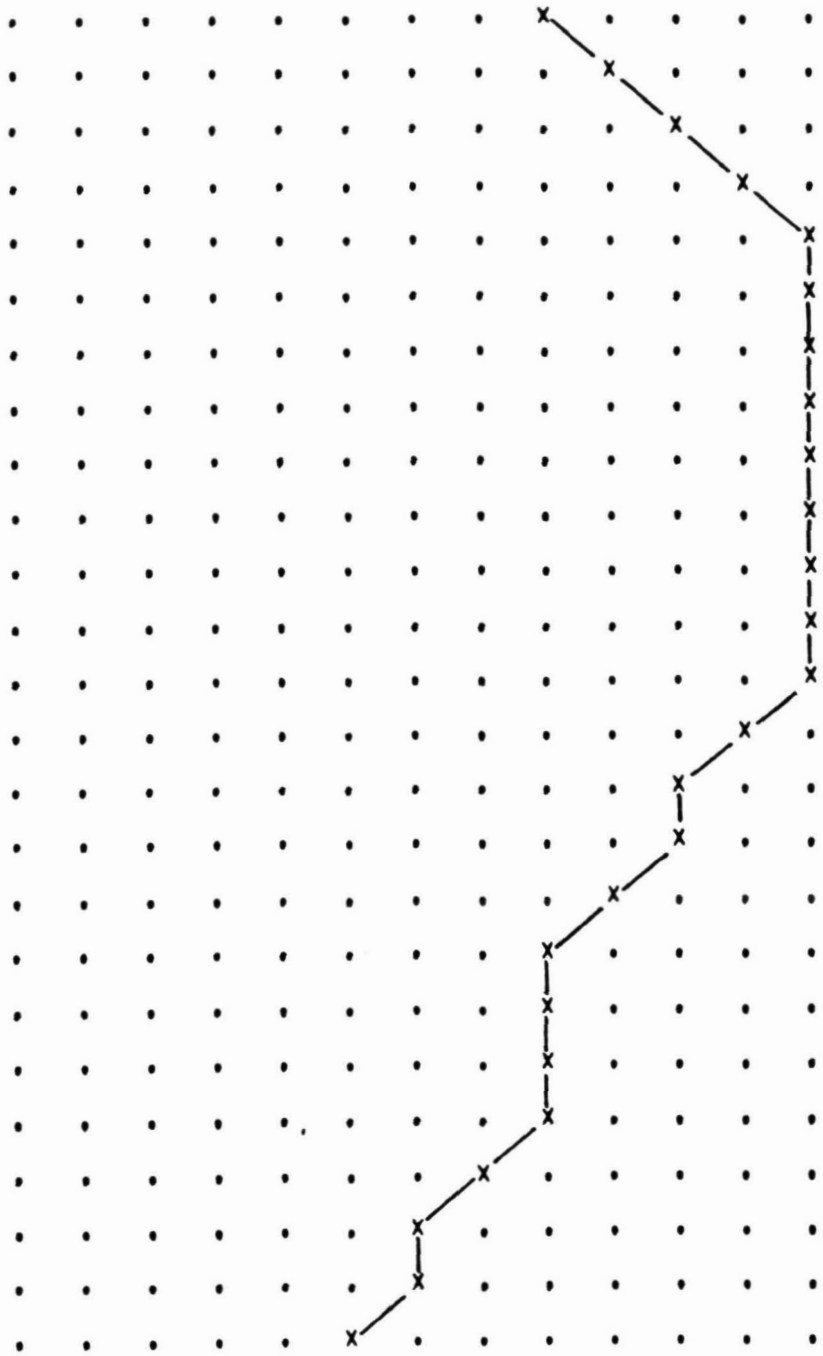


FIGURE 10

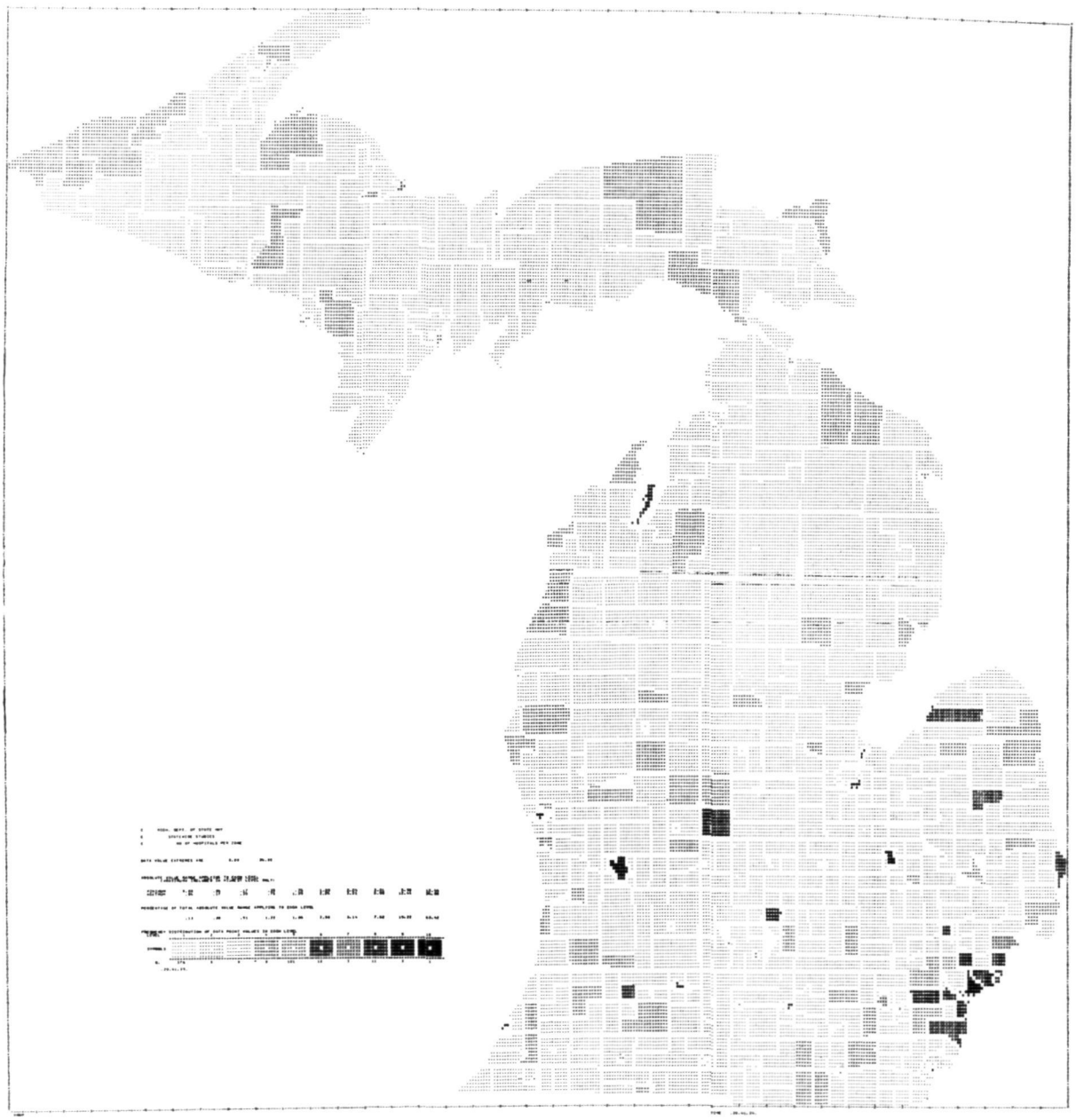


FIGURE 11

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IMPROVED RESOURCE USE DECISIONS AND ACTIONS THROUGH REMOTE SENSING

L-16

By R. Hill-Rowley, M. Boylan, W. Enslin, and R. Vlasin
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ABSTRACT

Michigan State University continues to be engaged in applications of remote sensing to a considerable variety of needs of governmental agencies and private organizations in order to facilitate the operational uses of remote sensing for improving management decisions and actions concerning resource uses. Cumulative experience reveals that operational applications are not all the same and that it is important to distinguish between at least two categories, namely (1) first generation, or direct-action; and (2) second generation or indirect, delayed-action applications. Making this distinction is crucial for many reasons, such as justifying proposed undertakings, guidance for research design, methodolgy requirements, budget allocations, and many others.

From among applications completed during 1974-75, seven case studies are offered in illustration of the many contrasts which can be drawn between first and second generation application studies. These include: (1) multi-agency river basin planning; (2) corridor assessment and route location for highway location together with improvement of county-level planning decisions; (3) improving timber management practices; (4) enforcement of new state statutes; (5) county-wide open space preservation; (6) land value reappraisal relative to property tax equalization; and (7) optimizing agri-business processing plant locations.

INTRODUCTION

Governmental agencies in Michigan at the state, regional and local levels are presently investigating and selectively implementing findings derived from applications of remote sensing techniques. Similarly, a number of private organizations are experimenting with this technology as a means of performing their missions more effectively. Michigan State University, with support from the Office of University Affairs of the National Aeronautics and Space Administration, has been actively involved in demonstration projects and a variety of technical assistance efforts to facilitate the operational uses of remote sensing for improving the decisions and actions for many of these management needs.

After several years of working with a variety of public and private user-agencies in experimenting with many different kinds of applications, the MSU investigators have developed certain perceptions about operational applications which they believe can be helpful to others. By this presentation, the MSU team wishes to offer for examination a summary review of a series of applications as illustrations of how some operational applications of remote sensing technology improved users' performance and improved decisions subsequently made and the effectiveness of actions ultimately taken ..... all of which steps are important phases in the process of "management". Management is viewed as a continuum within which there are many interwoven, interrelated strands, and two most essential functions of management for the purposes of this essay, are the <u>making of decisions</u> and the subsequent <u>taking of actions</u>.

Experience demonstrates that these phases or functions of management are interrelated to varying degrees; but relative to decisions and actions being influenced by remote sensing techniques, the factor of TIME-DISTANCE between the making of a decision and the taking of an action, together with the relative generality or specificity of information derived from the remote sensing input reveal a number of important distinctions which should be made between certain kinds of applications. Applications are clearly not one general, uncatalogued collection of remote sensing uses. The MSU experiences revealed that it is

important to make distinctions at least between what applications will (a) have direct impacts on a given situtation with a strong likelihood of generating, in a short interval of time, both decisions and implementing actions; and (b) those applications which will produce results over the long term with probably an appreciable time lag in the intervals before results begin to be displayed. These judgments then led to separating operational applications into two categories:

(1) First generation, or direct-action applications.
(2) Second generation, or indirect, delayed-action, multiple-faceted applications.

These two categories of applications are not sharply separable; they do overlap and sometimes conflict. This presentation is intended to show, among other features, for example, how the first generation, direct-action type does not only improve the effectiveness of the action(s) taken in support of decisions made; but provides reliable bases for making the decisions in the first place and shortens the time span between when the decisions are made and actions are taken.

Of the many possible differences between these two generation types, the following are worth noting:

1. For one type (first generation), the application is made for a very specific situation which can be located, identified, and evaluated in a span of weeks or days.. .....while in the other (second generation), the application is made in response to a considerable breadth of general, not immediately specific, needs; usually requires a long period of time (months, years) to identify and inventory characteristics; and evaluations don't usually lead into immediate decisions, let alone actions. Multiple decisions and actions can flow out of this latter type of application; and sometimes other uses for the derived information develop which had not been anticipated.

2. For one type the situation typically is small in scale, such as a functional site or a localized problem.....while in the other type the situation is usually large in territorial magnitute and/or ramifications, such as a river basin or metropolitan region.

3. For one type, the time intervals between initiation of investigation, completion of all research evaluation and reporting, making of decisions, and taking actions are characteristically brief. For the other, these intervals are much longer possibly stretching into multiple months or years.

4. For one, the remote sensing application makes possible the improvement of the quality and effectiveness of actions taken which lead from decisions previously made; but quite different.....such as the passing of an ordinance which establishes certain standards and/or prohibits certain kinds of practices. Remote sensing information may reveal violations of the ordinance thereby providing clear evidence for enforcing its provisions. Under the other type of application (second generation) remote sensing can provide a means for the mere purpose of making decisions more wisely and effectively, and may never lead to actions directly traceable to the original information base.

   Most importantly, the data derived from this type can be useful for other research operations, not necessarily related directly, by being combinable with other kinds of environmental and/or social information.

5. For one, all steps taken are unprecedented or innovative, calling for experimental routines to develop prototypes and indicators. For the other, after research design is tested and readjusted, much of the work becomes repetitive.

These several distinctions are crucial because they permit differentiation between two different needs that user-groups have, each requiring different information inputs which call for different methodologies and procedures for the research design, budget determinations and commitments, personnel logistics, tabulation and presentation formats and analysis routines, data storage and retrieval. The time dimensions can also be a governing factor as to feasibility and what routines need to be utilized.

As noted previously, these perceptions have emerged after many operational application experiences which were varied.....in type of situation, problem, etc.; in scope and magnitude of study; as to user-agency type; as to use of derived information; as to length of time intervals and overall time required to complete the mission.

From among those completed during the 1974-75 year, seven case studies are offered in illustration of the many contrasts which can be drawn between first and second generation studies. These selections include: (1) multi-agency river basin planning; (2) corridor assessment for highway routing and improvement of county-level planning decisions; (3) developing effective timber management practices in areas of scattered forest holdings; (4) enforcement of a recently enacted State of Michigan Soil Erosion and Sedimentation Control Act (P.A. 347-1972); (5) measures and procedures for local implementation of the new State of Michigan Farmland and Open Space Preservation Act (P.A. 116-1974); (6) appraisal standards and applications for land value reassessment relating to property taxes; and (7) optimizing agri-business processing plant locations.

METHODOLOGY

To make such operational applications possible, a basic methodology has to be structured as a prefatory step. Common to any applications research dealing with land features is the matter of following some system for classifying the characteristics of whatever features are to be considered. In Michigan, the Office of Land Use of the State Department of Natural Resources (OLU-DNR) formed a Classification and Referencing Advisory Committee which, in the spring of 1974, completed a working draft of a land cover/use classification system designed to be applicable to any part or all of the State's terrain. The system was especially structured to use both high altitude and spacecraft-generated imagery.

At the completion of the first edition of its classification system, the Committee recommended that it be field tested at the regional and local level and then be appropriately revised as needed corrections became evident. Such field testing was judged to be indispensable before distribution was made of the classification system for any general or particular use.

The Michigan State University Program had five of its investigators serving on the Classification and Referencing Advisory Committee, and because of the demonstrated interest and capabilities of the MSU staff in operational uses of remote sensing, the Program was requested to participate in the testing of operations, working jointly with the West Michigan Regional Planning Commission staff (WMRPC - a nine county official region headquartered in Grand Rapids) and with the State DNR Office of Land Use. In this joint effort the MSU team tested the classification system in a multi-level inventory of two counties and four townships in the WMRPC region.

The interpretation was accomplished using high altitude color infrared photography (1:120,000 and 1:60,000) and medium altitude black and white photography (1:40,000). Information obtained after interpretation was recorded for four hectare gird cells on computer coding forms which are compatible with the WMRPC computer-managed information system.

As a result of the findings of the combined field test and review activities, several changes were made to the system, such as sharpening or broadening definitions, dropping

some categories and adding others, etc. The intent of the overall effort was to develop a classification system which could serve the land cover/use inventory purposes throughout Michigan with as much versatility as possible. The MSU Program utilization experiences are repeatedly confirming the effectiveness of this system in a number of different features of operational applications. For example, many of the case studies about to be presented demonstrated that reliable comparability could be made between disparate applications by use of this classification system.

CASE STUDIES

The following presentation expands upon each of these seven case studies by providing summary descriptions of the principal features. (See Figure 1 for locations)

Case Study (1) Second Generation Type Application

Kalamazoo River Basin Study.- Land development in Michigan watersheds over the past two to three decades has generated an aggregate demand for uses of land and water for different purposes which has increased substantially the pressures on water and related land resources. This situation has intensified the need for workable and forceful policies which can monitor and manage resources so that further environmental degradation can be averted.

To achieve any progress in this effort reliable, useful, up-to-date information is needed. With so many different kinds of agencies playing a crucial role in conservation and monitoring processes, coordination is indispensable. In order to facilitate coordinated conservation measures, watershed planning agencies require the very best, latest, and in-depth information, especially information on current characteristics, land cover, and land use. In the past, resource information has been obtained principally via the "Conservation Needs Inventory" and from similar and related programs. All of these utilize an on-the-ground sampling methodology which are not only questionable as to accuracy; but do not meet the need for information on the spatial distribution of categories within a survey area. This situation has led resource planners and policy makers to search for more accurate, more complete, and less extrapolative data acquisition procedures.

The Kalamazoo River Basin, located in Southwest Michigan, is currently the subject of a three year resource planning effort designed to culminate in a series of action programs for the sensible use of land and water resources in the multi-county area. The principal units behind this effort are the River Basin Planning Group (RBPG) of the Soil Conservation Service, U.S. Department of Agriculture (SCS + USDA), the Economic Research Service, the U.S. Forest Service, and the Michigan Water Resources Commission.

Working in collaboration, these several agencies formed a Technical Committee which has been the action arm for the group. The Technical Committee prepared an extensive outline of information needs and research strategies which strongly emphasized the fundamental need for a detailed land cover inventory. The land cover inventory was considered as the major component of basic information which made possible such studies as analysis of flood plain problems, sediment control, identification of wildlife habitats, recreational planning, agricultural crop production and forestry.

At the request of the River Basin Collaborative, the Michigan State University Remote Sensing Research Program was requested to conduct a land cover inventory for the entire 8,600 square kilometer Kalamazoo Basin. The inventory was completed in two stages. The first involved a demonstration of the scope and efficiency of available RB-57 color infrared imagery (CIR) in providing land characteristics data required by the RBPG for the component 2,800 square kilometer Upper Kalamazoo Watershed. A comparative cost analysis

framework used to evaluate different methods of interpretation and image types possible in completing the task was also part of the overall mission.

Upon the successful completion of these tasks, the second stage of inventory was undertaken on a contractual basis. This consisted of inventorying land cover characteristics for the substantial remainder of the Kalamazoo watershed.....the 5,800 square kilometers of the Lower Basin. These data were derived from commercially flown and processed color infrared imagery at 1:31,680, with all costs shared by the participating agencies. At the same time the counties within the watershed participated with supplemental funding to have additional territory photographed for those remaining segments of each county that were outside the boundaries of the watershed configuration.

The data collection for this Lower Basin utilized some notable differences in methods, in contrast to those employed for the first stage, i.e., the Upper Basin, namely: (1) commercially flown and processed CIR imagery was used; (2) the user-agencies paid for the imagery; (3) the classification system was revised; (4) inventory data were recorded on U.S. Geological Survey topographic quadrangle base maps; and (5) land use area distribution was calculated in terms of soil associations.

A summary of the inventory characteristics for the combined Upper and Lower Kalamazoo Basins project is displayed on Table I. An illustration of the method of data portrayal on maps is displayed by one example in Figure 2.

Uses of the Kalamazoo Basin Information.- As previously noted, this category of application, the "second generation", or "indirect, delayed-action" type implies long term and, very likely, indirect uses for the derived information to serve as intelligence for the planning and management of the lands and waters of the river basin system.

Already information developed for the Upper Basin (completed in 1974) is being utilized. As reported in an earlier paper of the MSU program in March 1974:

> Several user agencies have found applications for the information obtained in the Upper Kalamazoo Watershed pilot study. The U.S. Soil Conservation Service is applying the study data to analyze flood plains, sediment problem areas, land use, and agricultural water use and pollution. The SCS is also making use of the data in conjunction with the Michigan Department of Natural Resources (DNR) in an examination of fish and wildlife habitats, and area recreational developments. The SCS also plans to use the data in coordinated studies with the Natural River Section of the DNR to analyze natural and scenic river and unique land areas, and in environmental and esthetic quality planning. This agency is also utilizing the study data for defining various activities on land that have been designated as prime agricultural land, and also for determining erosion rates for particular soil groups on specific land uses. Finally, the SCS is cooperating with the Economic Research Service of the USDA in updating and validating the Conservation Needs Inventory.
>
> The U.S. Forest Service is using the inventory data in several analyses. The forest type and acreage data contained in the inventory are being correlated with soils information to determine productivity estimates of forest resources in the Upper Kalamazoo Watershed. The Forest Service is also using the study data to compile coefficient indices which represent qualitative evaluations of multiple uses of a mixture of resources in a given area. The coefficient indices will assist in determining management strategies for the optimum multiple use of resources in the watershed. This agency is also using the data in specific studies designed to analyze forested areas near urban concentrations to determine if they should be preserved.
>
> In addition to use by federal and state agencies, county planning commissions

will also use the data to update and validate land cover and use information in their counties. ("Resource Inventory for Multi-Agency Watershed Planning". W.R. Enslin, B. Richason III and M.J. Bennett. In Remote Sensing of Earth Resources Conference. Volume III. pp. 653-670. The University of Tennessee Space Institute. Tullahoma, Tennessee. March, 1974.)

For a second generation operational application, these are quite an extensive and varied catalog of early uses. Such prompt application of derived information suggests a long term unfulfilled need for solid, timely, relevant comparative intelligence on land and water characteristics developed on a unified, regional scale.

By completing this dual-basin study, an accurate, cost-efficient, general inventory of land use has been generated which will provide the basis for many possible series of decisions in several spheres. In time some of the decisions will be translated into actions; but it is conceivable that other information needs may be required for some actions to be effectively implemented.

Case Study (2) Second Generation Type Application

Grand Traverse County Special Environments Inventory.- This study was a combination of a general land cover inventory and a special environments analysis conducted in collaboration with a group of public agencies. Grand Traverse County, located in the northwest corner of Michigan's Lower Peninsula, urgently needed a network of land and other resource information for multiple purposes. At the request of the Grand Traverse Bay Regional Planning Commission (GTBRPC), the Michigan State University Remote Sensing Program joined in the collaborative endeavors of the County Planning Commission, the Michigan Department of State Highways and Transportation, and the Office of Land Use within the Michigan Department of Natural Resources (DNR) in developing a general 24 category land cover inventory together with the identification and "flagging" of a series of special environments. This dual final product provided a wider scope and capability than was required in the Kalamazoo Basin project.

The special environments classification consisted of 34 special features which provide information relative to prime agricultural lands, wetlands, steep slopes, forested areas, critical soil conditions, and areas of prominent social values, including: (1) developed, commercial, residential and industrial areas, (2) scenic areas, (3) historic areas, (4) unique wildlife areas, and (5) precious wildnerness situations. A summary of the inventory characteristics for the Grand Traverse Project is given in Table II.

The inventory data were derived from 1:36,000 color infrared imagery using a four hectare grid and were recorded on specially-designed computer coding forms. These forms were constructed so that up to six land cover and seven special environment codes could be recorded for each four hectare cell.

With the raw data in this form, a specific locational indicator for each cell was assigned which then offered the possibility of analysis, evaluation and presentation of the generated information by computer methods. Real world constraints and priority weightings can thereby be established as operating rules for information retrieval by which means information can be made accessible and useful for a variety of disparate uses.

One display technique which has been used is a plotter routine which depicts the inventory data through a combination of different designs and color combinations (see Figure 3). In addition, a sorting process can be used to plot only areas with selected combinations of land uses and special features and, possibly later, soils and topographic conditions. In addition to evaluation of socio-cultural parameters of intensive land use conditions, this procedure facilitates land suitability analyses from a physical characteristics standpoint.

Uses of the Grand Traverse County Information.- Immediately upon completion of the inventories, the data were put to use as a resource base for County planning decisions and continue to serve as a framework for local government participation in highway corridor evaluation and selection. The GTBRPC is using the data to locate the best future growth areas for residential, commercial, and industrial land uses without causing an adverse impact on sensitive environmental areas. For example, the optimum site location for a potential industrial park site was derived by identifying those cells which met the required site criteria of isolation from residential areas, adequate transportation facilities, sufficient contiguous areas for expansion, etc. In addition to these kinds of uses, the inventory information is being applied to locate optimal low environmental impact highway corridors, using weighted values for each land use according to specific geographical areas, primarily the unincorporated territories of townships.

The land cover inventory and particularly the special environments identifications allow a tremendous variety of corridor options to be derived and made available for comprehensive and coherent local discussion and evaluation.....indispensable processes for facilitating improved decisions for identification and selection of an optimum highway corridor. At the State level, the Department of State Highways and Transportation is closely monitoring the utility of special environments intelligence. If experimental applications can demonstrate that this additional method fulfills an adequate function in assisting with highway corridor selection, the procedure can become a required element for future corridor studies.

Although the time-distance interval between decision and action is much less than in the Kalamazoo Basin study, this Grand Traverse endeavor is still a good example of the second generation operational application. To illustrate, data were made available to the Grand Traverse Bay Regional Planning Commission in January 1975 whereby that body was provided with land cover information on which to base planning decisions. A number of decisions were rather promptly made possible. An alternate site for a new industrial plant was derived on the basis of the information provided by the dual inventory. The location and construction of a major new highway, including the selection of an optimum corridor and the location of the specific right-of-way within the expanse of the corridor were made with the fullest possible bases of reliable and up-to-date information, and decisions were able to be made within a comprehensive framework. The Regional Planning Commission is busy making decisions daily as to development configurations with local units of governments which are rapidly developing local/comprehensive development plans. Now that a regional land cover and special environments information system are operational, it will be only a matter of routine functions to keep such a system updated and expanded upon as time advances. This Grand Traverse situation is one which offers encouraging confirmation of the thesis that more competent, effective, and broadly-based decisions and actions will emerge if the informational base is adequate.

Case Study (3) First and Second Generation Type Application

Mason County Forest Inventory.- Timber management, harvesting, and marketing comprise the second largest component of the economic base of Mason County, Michigan. Profits, salaries, tax revenues, and other income are derived substantially from wood-based industries in the County. The viability of this economy is seriously handicapped by the largely fragmented holdings of privately-owned forested lands. Over 80 percent of the forest land in Mason County is privately owned, ownership patterns ranging from very small to moderate-sized holdings; but the small tracts are the most common. The interweaving of national and state forest tracts amidst the private lands only further complicates the management, survey and evaluation of timber stands. Another complicating factor is the great variation in the marketable condition and quality of existing individual stands.

One serious aggregate resultant of the operation of these many deterrents and obstacles is the creation of a pseudo-shortage of marketable timber; whereas, in actuality, Mason

County is rich in mature timber resources.

The logistics of wood processing industries require a minimum tributary supply of timber within economic haul limits to sustain a profitable mill facility. Production industries are forced to curtail operations of existing mills when the supply of raw materials is below pre-determined economic production-handling volumes. Consideration of expanding existing mill facilities or building new ones is out of the question in the face of any category of shortage.

Mason County is in the potential position of losing its wood-processing industries and thereby its at-hand market facility. Unless ways can be found to identify, manage, and bring to market the forest resources of the area, the County community can foresee the possibility of having the mill abandoned. At present the forest raw material supplies are indeterminate, widely fragmented, dispersed, and in a condition of pseudo-shortage. In the face of such a contradiction, officials in public agencies and private timber industries turned to remote sensing as a possible means to solving a serious problem.

Through the intervention of the West Michigan Regional Planning Commission, the Michigan State Program was asked to work with the local Soil Conservation District officials in furthering the implementation of an existing program for developing effective timber management and wood harvesting programs under the rubric, "Operation Woodchuck".

Uses of the Mason County Forest Inventory.- To satisfy a need for information on the location and condition of forest resources, color infrared photography at scales ranging from 1:36,000 to 1:120,000 were used to classify the forests into six species groups, three stocking levels, and three maturity classes within a minimum type size of four hectares. Figure 4 represents one of the forest cover type maps prepared for the Mason County project.

The forest resource maps are being used by the Mason-Lake Soil Conservation District, by the West Michigan Regional Planning Commission, and by the timber processing industries in that area. Uses have already begun which include the development of effective timber management and programming of timber havesting for the coming years. The representatives from industry are reporting gratifying results in identifying and locating various grades of timber all within reasonable marketing parameters.

Initially this forest inventory application was conceived as a second generation operational application. Forest resource data were required for an information system being developed by the West Michigan Regional Planning Commission. The system was intended to form a basis for a range of local resource development and management programs. Out of this larger systems program emerged the potential for helping resolve the timber marketing problem, and so this potential is being quickly realized. Forest type maps are now allowing the identification of merchantable stands within the County, and so, in its continuing development, the Mason County study has become for the commerical timber interests, a direct-action, quick-turn-around, first generation operational application leading to direct on-land actions by individual land owners and timber marketing firms. The original intent will still be realizeable over the future months and years as other resource management processes become structured and operational.

Comment.- The remaining four case studies illustrate first generation operational applications. As will be noted, these will highlight direct decision-action applications. While each application is entirely different from the other three .....varying elements in different contexts.....they share a common characteristic in serving a specific clear-cut statement of a situation requiring attention, which, when measured and evaluated, leads to making decision with confidence, and finally, to the taking of definitive actions within a short time-distance interval.

Case Study (4)

Farmland and Open Space Preservation - Wayne County, Michigan.- Under a new statute enacted by the Michigan Legislature in 1974, counties have been designated as the agencies responsible for executing the necessary actions in establishing policies and long-range plans for categorizing appropriate lands as desirable permanent open space, and then taking the necessary actions to implement the reservation of such lands. (State Of Michigan: Farmland and Open Space Preservation Act P.A. 116, 1974.)

Wayne County, Michigan, the home county for the City of Detroit, was the first in the State to initiate implementation of this Act. There were no precedents or guidelines for this kind of development strategy; so considerable consultation and experimentation was essential. When invited by the Wayne County Planning Commission (WCPC) to contribute the potential capabilities of remote sensing to this study, the MSU Program first loaned RB-57 color infrared imagery to the Planning Commission staff, then developed, in collaboration, a land classification system, provided extensive training sessions for Planning Commission personnel, and continued to contribute technical inputs, such as interpretation of imagery. With such assistance, the staff of the WCPC developed an updated inventory of land use for the undeveloped portions of the County. This survey showed, suprisingly, that this very urban County of Wayne has 20 percent (33,381 hectares) of its land still in agricultural uses and other unimproved open space. About one half of this area (16,600 hectares) is currently inactive and unimproved - producing no economic return.

In a policy format, the County Planning Commission declared intent to seek the establishment of a pattern of lands to be reserved as permanent open space. The distribution and location of the ultimate land reservations were to be derived from the future growth configurations emanating from the previously drafted County "development strategies". When these determinations were eventually drawn up, series of public hearings were conducted all around the County to inform residents and officials of the intent of the program, what benefits could accrue, and how implementation would occur. In concluding this analysis phase, the Planning Commission committed the County to reserving a definite number of hectares in accordance with a determined, designed physical configuration.

The new Farmland and Open Space Act provides for implementation by authorizing the execution of contracts with owners of designated open space lands whereby the owner yields development rights and/or easements to the County. In return, the owner receives property tax relief and freedom from special assessments for improvements of no benefit to his land uses. This process insures that a given property will remain in an agricultural or open space use for a period of 10 years or more.

To be fully implemented, however, the zoning ordinance of any local government unit agreeing to participate in this program must be amended to incorporate provisions which will accommodate the special features of land reservation provided for in this State Act. In addition, the local zoning ordinance must also incorporate revised land use district configurations to mesh with the County development strategies plan. The local unit must also formally express concurrence with the policies of the County.

In this case of Wayne County, the optimum location and extent of these open space areas were determined through the use of remote sensing imagery and related techniques. Interpreting soil characteristics, land cover and slope, alternative patterns of open space were constructed. These kinds of information were derived from NASA high altitude (RB-57) color infrared photography. By use of appropriate interpretation, it was feasible to interpret land characteristics of substantial areas in a very short time. The whole County was interpreted and plotted in a matter of weeks. The processes of review and evaluation, via public meetings and deliberations by governmental officials required, however, considerably more time.

To date, five townships in Wayne County have progressively decided to join in this open space preservation program. At the time of preparing this paper, several other local units have various versions of land reservations under consideration. This effort actually has produced other benefits in addition to retaining agricultural productivity of farmlands and the aesthetic values of holding substantial lands in open space condition. The Wayne County study has provided a prototype procedure that has been tested, refined, and restructured in the Wayne County application. The MSU Program is arranging to work with other Michigan Counties to assist in further implementations of Act 116.

Effectuation of policies and programs like the Michigan Farmland and Open Space Act will have substantial impact on the character and nature of human settlement over the next decades; for it will be by means of such concepts that the continuing accretions of undifferentiated urban sprawl that has characterized urban growth over the past 50 years will be arrested and hopefully diverted into more livable and effective patterns.

While long range implications of this kind of legislation are very important, successful implementation will depend to a large degree on an information base which can be derived in a short interval of time. The one major - and most promising and reliable - means for securing the needed information is that of remote sensing technology. As the versatile capabilities of remote sensing become better known, more and faster progress toward essential societal and environmental reform can emerge as technical capabilities make innovative concepts appear achievable.

Case Study (5)

Soil and Sedimentation Control - Antrim County, Michigan.- The Antrim County Planning Department (ACPD) has used remote sensing in an even more direct manner to implement the State of Michigan Soil and Sedimentation Control Act (P.A. 347, 1972). Color infrared photography provided an expeditious, legally acceptable means for both evaluating site construction plans required for earth-change operations and for detecting potential violations of codes and ordinances. Two examples of situations on Torch Lake in Antrim County illustrate this capability of remote sensing for helping evaluate possible violations and earth change requests.

The Act requires that a site plan be approved and an "Earth Change" permit be obtained for any operation which will change the configuration of the ground form.....i.e., an "earth change".....if that activity is located within 500 feet of a lake or stream. A citizen complaint received by the ACPD in August 1974 suggested a possible violation (see Figure 5). The alleged violator was of the opinion that the road construction underway was 600 feet from the nearest point on Torch Lake (the distance A-C on Figure 5). Using the photography, the ACPD determined that in fact the site was 365 feet from the Lake (the distance A-B on Figure 5). A stop-work order was issued to the violator based on the data derived by photo interpretative techniques. The order was initially challenged and a ground survey requested; but both the violator's attorney and the County Prosecuting Attorney agreed that the photographic evidence was legally acceptable, and the order stood.

In another case, also in Antrim County, a site plan and request for an Earth Change permit was submitted for the construction of a groin wall on Torch Lake. The proposed wall (approximately 24 feet long) would be at the north of the owner's property line on the northwest end of Torch Lake (Point A, Figure 6). There is an existing groin wall (Point B, Figure 6) that would be removed when the new wall was constructed. In evaluating the site plan, the ACPD assessed the potential effects of the 24-foot groin wall on the present lake erosion and sedimentation patterns through an analysis of these patterns depicted on 1973 color infrared imagery. A northeasterly and southern lake current (see points D and C, Figure 6) converge at this general area. The resultant heavy turbulence zone creates a sucking and cutting action which promotes shoreline erosion immediately to the north of the present groin wall. The Department decided that a 24-foot long wall at the proposed location would

intensify this erosive action, thus an Earth Change permit was denied. Extending tangents from the lake shoreline on both sides determined the location and maximum length (12 feet) of a groin wall that the Planning Department was prepared to allow (Figure 7).

Both examples show that remote sensing technology can provide a timely, accurate, and in some cases, the only comprehensive means to evaluate legitimate Earth Change permit requests and also offer an effective and legally sound method of enforcing the Soil Erosion and Sedimentation Control Act.

Case Study (6)

Land Value Appraisal - Charlevoix County, Michigan.- The Charlevoix County Equalization Department is using color infrared photography to reassess more accurately land values, particularly for remote and isolated properties. Beaver Island, located 12 miles off the coast into Lake Michigan provided the County with an especially difficult assessment problem. Large scale black-and-white photography was available for the island; but this imagery did not permit adequate identification of swamp and higher ground which are the two basic criteria for property evaluation in such terrain. Moreover, due to the inaccessibility of the terrain, usual ground inspection methods were deemed unfeasible. Land value appraisal and consequent property taxes levied for the Island, using such limited information as these black-and-white photos, were inevitably approximate and most imprecise. Using rudimentary interpretation and projection techniques, the Equalization Department personnel, with CIR imagery provided by the MSU Program and MSU interpretative assistance, were able to produce a simple land characteristics map of Beaver Island as well as of several other islands in the County. All property valuations for the islands have been reassessed and changed where appropriate on the basis of these mapped data backed up with photographic evidence.

Appraisal of land value is becoming an increasingly complex and detailed process. Color infrared photography used here without sophisticated equipment provided an accurate and time-saving method which facilitated new value appraisal and assessment methods and achievements.

Case Study (7)

Optimizing Agri-Business Processing Plant Locations.- In the Saginaw Bay area of Michigan, beans, corn and small grains are important crops requiring immediate processing for storage and marketing. For effective operations, it is economically and technically crucial that processing facilities be located within areas of high crop production. In addition, recent increases in both crop acreage and yields have created a need for expanded processing facilities at new sites. In the past, elevator location decisions were a "hit-or-miss" process based mainly on subjective and unscientifc procedures and criteria. Crop Reporting Service statistics regularly indicate production totals by counties. However, elevator service areas, with a radius of 13 to 16 kilometers, are areas substantially smaller than a county, and many include parts of more than one county. In the absence of data on the spatial distribution of specific crop acreages within each county, processing firms lack adequate information for their locational decisions.

The main criteria for optimizing processing plant and elevator locations are: (1) centrally located in relation to the county's largest crop production area; (2) adequate highway (Class A) accessibility; and (3) railroad accessibility. In the past, this information was acquired from windshield surveys by company personnel. No quantitative acreage evaluations were possible, and only a generally-defined service area could be identified. The business firm would seek an elevator site with adequate accessibility within this generally defined service area.

MSU Remote Sensing Program personnel, in cooperation with one particular large agribusiness firm are investigating the use of satellite and NASA research aircraft imagery to acquire an improved data base for corporate decisions aimed at optimizing the location of future elevator facilities with respect to crop production areas and to the criteria previously enumerated.

In the instance of this case study, the research work is in progress; a completed analysis with consequent decision-action results cannot yet be reported, except that in the fall of 1974 the MSU Program did a pilot study for this firm using whatever imagery was available and fitting in the analysis to meet very limited time constraints (placed on the user by market pressures). The business organization was most gratified with these particular results, and accordingly has concluded arrangements with the MSU Program to continue in 1975 with studies in other areas of the State in order to determine optimum locations for at least three additional processing plants.

Investigations by the MSU Program will be designed to meet these stated needs. For each county selected, four categories of information will be identified:

(1) amount and distribution of tillable land in the county;

(2) highway and railroad accessibility;

(3) identification of the present distribution of beans, corn and small grains;

(4) potential crop productivity based on soil management groups.

The investigators will use Skylab imagery to locate and define broad crop service areas containing intensive cultivated land and good transportation accessibility. In each broad service area the categories of information (previously cited) will be identified and delineated from NASA RB-57 high altitude color infrared photography. The mapped information as well as soils information for these selected areas will be gridded and coded for computer storage and then alternative plant sites will be selected.

For each identified potential site, a routine will calculate total area in each type of agricultural use and will estimate potential crop productivity for assigned service areas. Finally, recommendations for specific sites for the location of new processing plant elevators will be made. It is important to emphasize that during most of these analysis operations, the business firm personnel will be equally involved in the processes except where special technical skills are needed. Through participation, the user will learn more about the features of the business operation, perhaps discern new relationships of dynamics, etc. But, more directly important to the MSU involvement is that another user will have become knowledgeable of the appreciable utility of remote sensing.

SUMMARY AND CONCLUSIONS

The original intent of the remote sensing program at Michigan State University was to experiment with remote sensing technology to determine its usefulness as a means for deriving more complete and reliable information concerning characteristics of land cover and use than conventional methods provide. In addition, factors of economics of time, materials, and costs were important criteria for concomitant evaluation. Finally, it was hypothesized that remote sensing could provide information which had not heretofore been available in either kind or scope which could be derived from new generations or sets of "indicators".

The intended usage for such enriched intelligence was to provide public and private policy/decision makers with much more and greatly improved information upon which to formulate policies, make decisions, and take actions relative to the effective managment of land and other natural resources.

The efforts of the Program continue to be directed at this progression of objectives; however, intermediate application experiences have been utilized as means for developing needed knowledge and capabilities for investigators. A series of operational applications, of considerable variety, have been engaged and brought to conclusion which have been most valuable for advancement of wisdom and skills.

One important feature of these applications, or "case studies" was the realization that such endeavors are not all the same, that they are considerably different and have to be selected, designed, and executed by utilizing methods singularly appropriate to each. Repeated endeavors clearly indicated a broad primary classification, namely, those which generate prompt, direct responses in terms of decisions and implementing actions (categorized as "first generation"), and those which produce delayed and indirect reactions over time to the information garnered and generated (categorized as "second generation").

This primary distinction has proven very helpful in evaluating possible new engagements. After the first year or two of working at convincing possible users of the relatively unknown utility of remote sensing, the reverse is occurring, with multiple requests coming unsolicited to the Program for assistance in operational applications. It has become mandatory that selectivity be employed in the situations to which the investigators wish to become committed. Some applications are accepted on a contract basis with the user paying for the routine, repetitive kinds of work; but the majority of engagements selected are those which will allow further testing of methods and producing new competencies - both kinds of benefits are moving the Program closer to its objectives.

The illustrations utilized as "case studies" in this presentation are intended to demonstrate the essential distinctions between first and second generation applications and to share some lessons learned for selecting additional case studies and in the planning-design management and execution. As a final note, however, it is important to note that in all these applications, the user-agency was included as a participant in order to maximize understanding of the processes whereby information and findings are derived, allowing the progressive formulation of tentative decisions, and generating early anticipation of what actions might need to be taken as well as discerning other possible uses for the information. Additionally, the agency personnel were many times most helpful in pointing out the likely non-productivity of moving along certain lines and suggesting more promising directions. As each application experience is completed the investigators realize that new methods and capabilities have emerged and that new, important converts to remote sensing technology have been made.

TABLE 1. KALAMAZOO BASIN INVENTORY CHARACTERISTICS

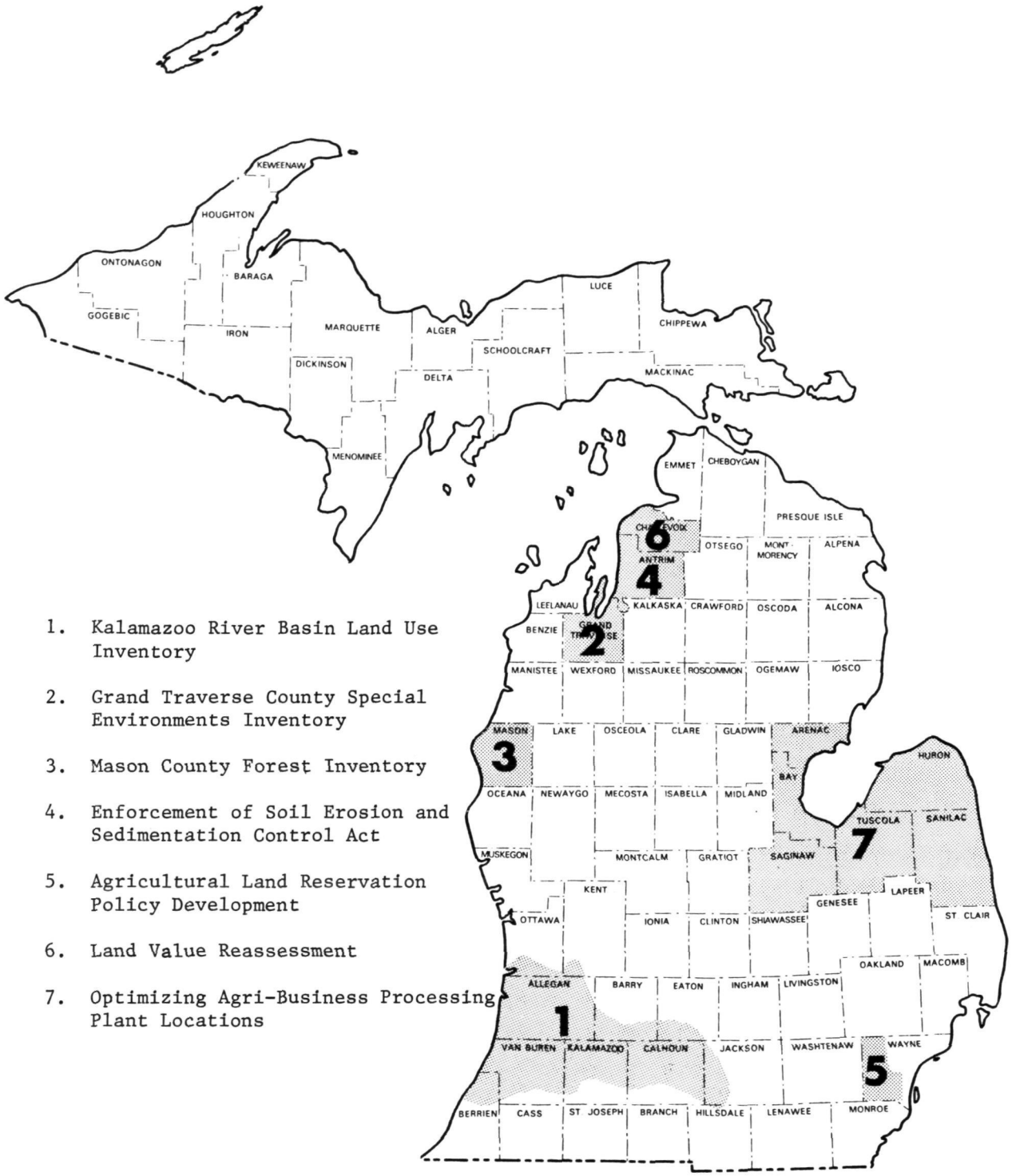
Area	Land Cover/Use Classification	Photography Used	Minimum Type Size	Base Map	Land Use Area Tabulated By [a]
Upper Kalamazoo Basin (2,800 sq.km.)	1. Cropland 2. Orchards 3. Vineyards 4. Small Fruits 5. Pasture, Fallow Land, Forage Crops, Sod & Other 6. Deciduous Forest 7. Coniferous Forest 8. Mixed Forest 9. Brushland 10. Marshland 11. Urban Residential & Commercial 12. Urban Industrial 13. Urban Construction 14. Rural Built-up 15. Water 16. Open Pits 17. Sand Dunes 18. Roadway System	1:60,000 and 1:120,000 Color Infrared	4 ha	County Highway Maps [b]	Township, County, Sub-basin and Basin
Lower Kalamazoo Basin (5,800 sq.km.)	1. Cultivated Cropland 2. Hay, Pasture & Inactive Agriculture 3. Tree Fruits 4. Bush Fruits & Vineyards 5. Ornamental Horti-culture 6. Confined Feeding 7. Broadleaved Forest 8. Coniferous Forest 9. Mixed Forest 10. Brush 11. Forested Wetlands 12. Marsh 13. Shrub Swamp 14. Open Water Vegetated 15. Residential 16. Commercial, Services and Institutional 17. Industrial 18. Extractive 19. Transportation 20. Other Urban 21. Water 22. Barren Land	1:31,680 Color Infrared	4 ha	Mylar Copies of U.S.G.S. Topographic Quadrangles	County, Sub-basin, Basin and Soil Association

[a] Area calculations based on a 16 hectare dot grid.

[b] After the completion of the Lower Kalamazoo Inventory the Land Cover/Use delineations for the Upper Kalamazoo Basin were transferred to Mylar copies of U.S.G.S. topographic quadrangles.

TABLE 2. GRAND TRAVERSE COUNTY SPECIAL ENVIRONMENTS INVENTORY CHARACTERISTICS

Code	Land Use	Code	Special Environment (Flags)	Photography Used	Minimum Type Size	Output
11	Residential	01	Roadways	1:36,000 Color Infrared	4 hectare Cell Size	Computer Graphics
12	Commercial, Services, or Institutional	02	Railways			
13	Industrial	03	Airstrips			
14	Extractive	04	Bridge			
15	Transportation Communications and Utilities	05	Powerline			
		06	Gas line			
18	Mixed Urban and Built-Up	07	Oil or Gas Wells (and Storage)			
19	Open and Other Land (outdoor recreation, cemeteries)	08	Confluence of Two Streams			
		09	Mobile Homes			
21	Cropland, Rotation, and Permanent Pasture	11	Ponds			
		12	Great Lakes Shoreline Zone			
22	Orchards, Bush-fruits, Vineyards, Horticulture	13	Inland Lakes Shoreline Zone			
		14	Linear Stream Zones			
23	Confined Feeding Operations	15	Water Access Sites			
29	Other Agricultural Land (farmsteads, green houses, exercise race tracks)	16	Effluent in Lake or Stream			
		17	Impoundment Structures			
		21	Submerged Aquatic Vegetation			
31	Broadleaved Forest	22	Emergent Aquatic Vegetation			
32	Coniferous Forest	31	Forest Plantation			
33	Mixed Forest	32	Forest Fire Area			
41	Forested Wetlands	33	Drowned Forest			
42	Non-forested Wetlands	41	Irregular Topography			
52	Brushland	42	High Bluff or Cliff			
61	Streams and Waterways	43	Low Bluff or Cliff			
62	Lakes	44	Sand Dune			
63	Reservoirs	45	Drumlin, Esker, Kame, Kettles			
92	Beaches	46	Sinkhole			
93	Sand Other than Beaches	47	Islands			
94	Bare Exposed Rock	48	Peninsula			
96	Transitional Areas	50	Terraced			
		61	Cemetery			
		62	Sanitary Landfill			
		63	Junkyard			
		64	Scenic Turnout or Rest Area			



1. Kalamazoo River Basin Land Use Inventory
2. Grand Traverse County Special Environments Inventory
3. Mason County Forest Inventory
4. Enforcement of Soil Erosion and Sedimentation Control Act
5. Agricultural Land Reservation Policy Development
6. Land Value Reassessment
7. Optimizing Agri-Business Processing Plant Locations

Figure 1. Location of Michigan Application Case Studies.

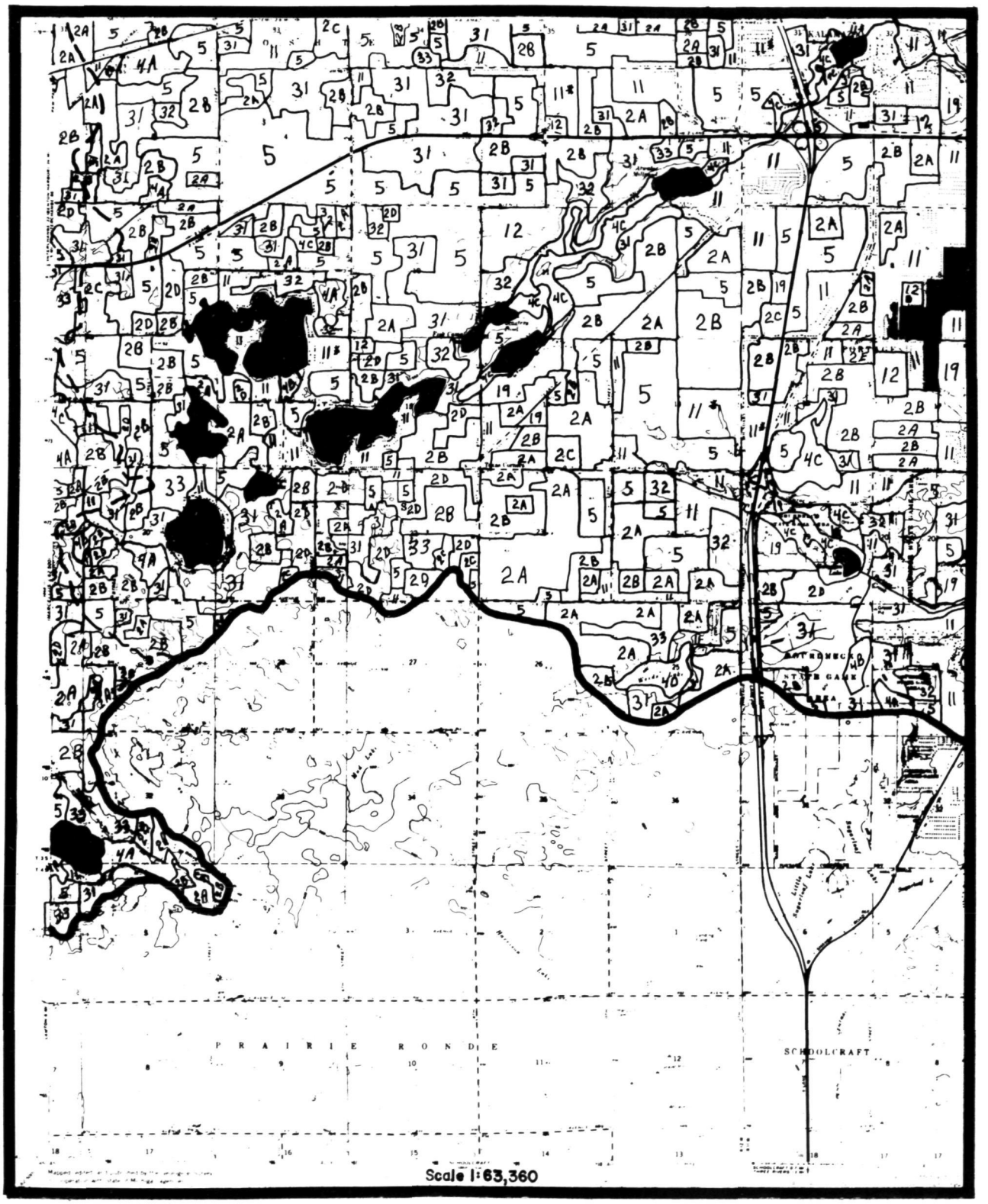
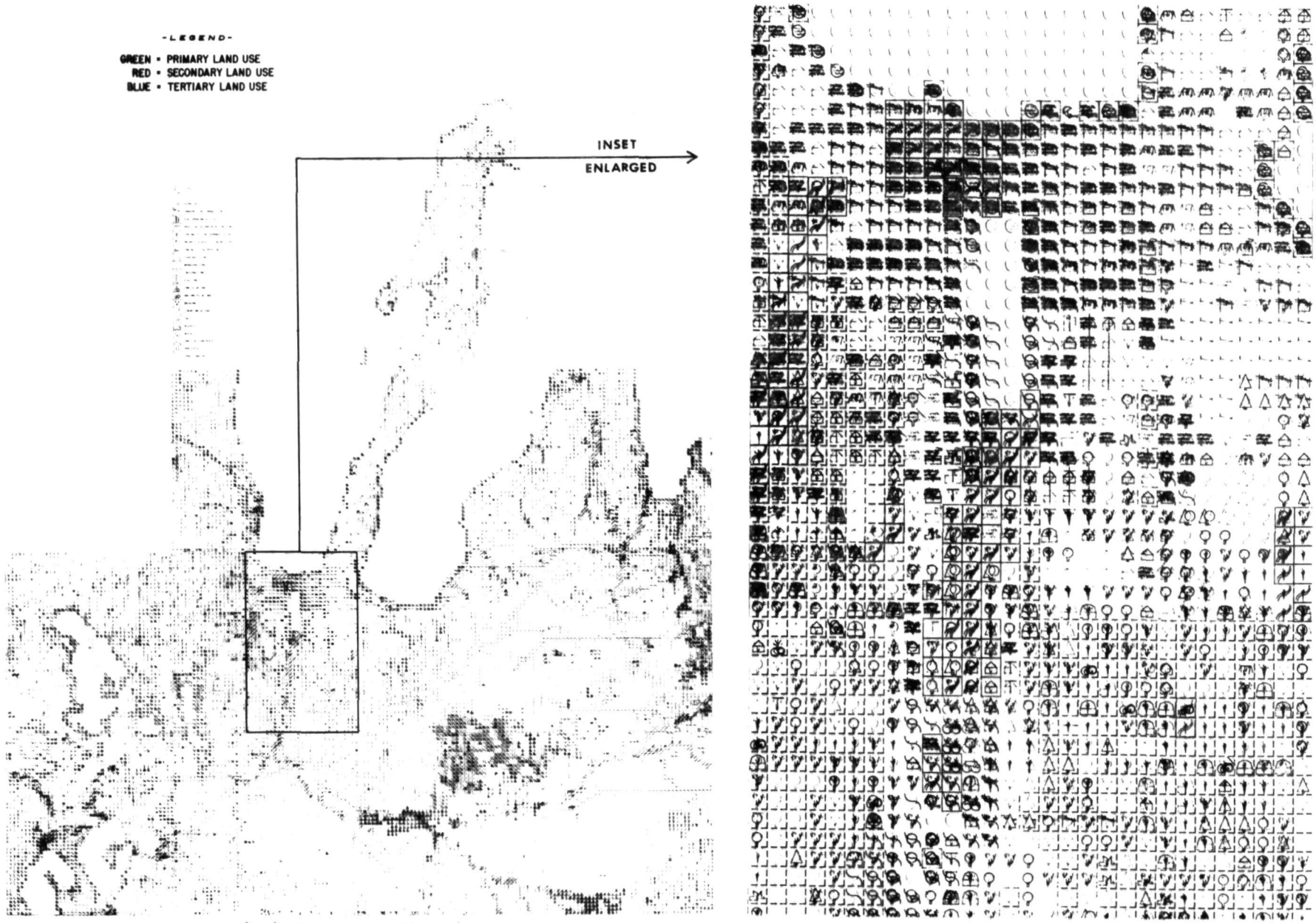


Figure 2. Kalamazoo River Basin Land Cover Map for the Schoolcraft N.W. Michigan U.S.G.S. Topographic Quadrangle



(original in color)

Figure 3. Land Use and Special Environments Computer Plotter Map
Grand Traverse County, Michigan

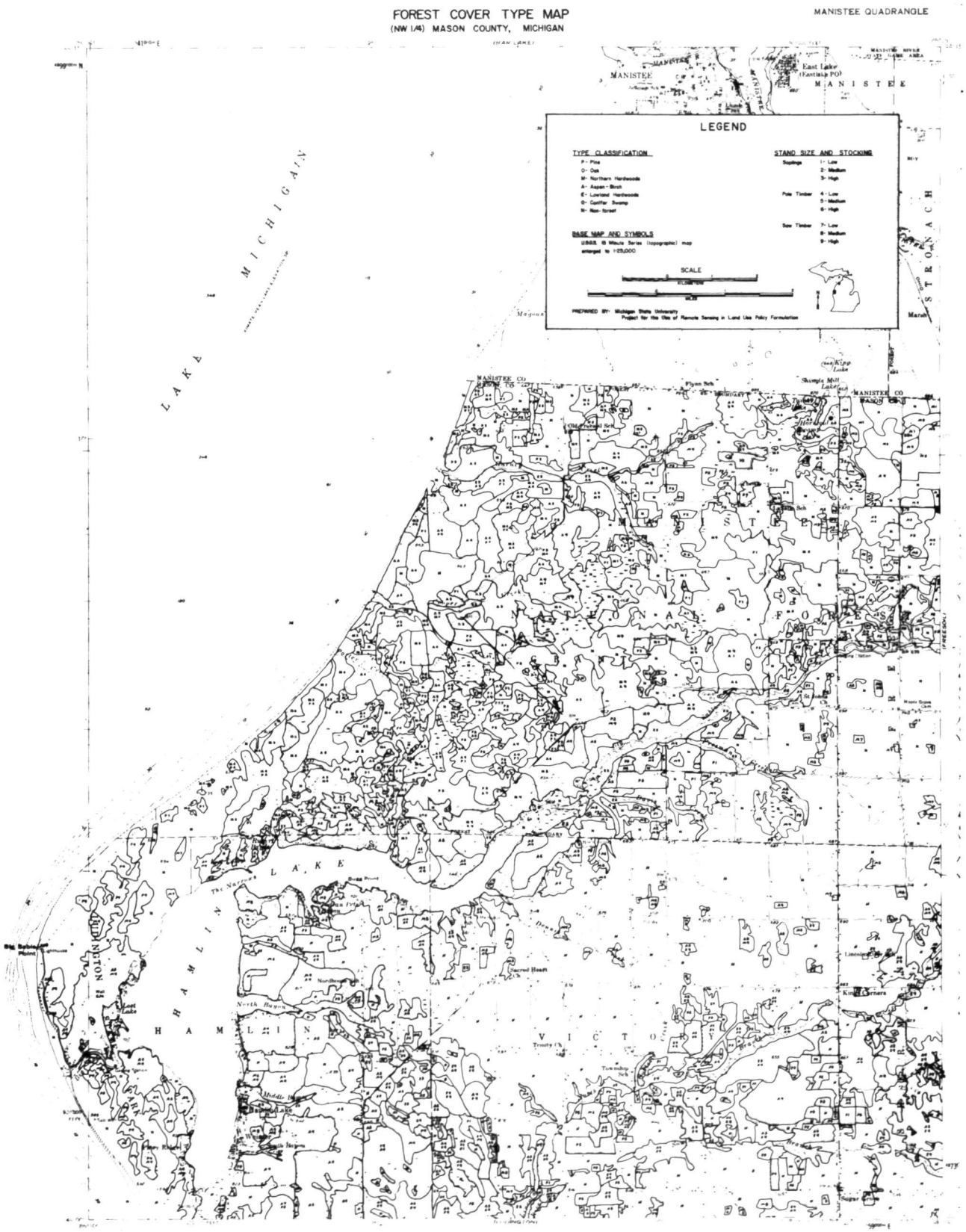


Figure 4. Forest Cover Type Map (NW¼)
Mason County, Michigan

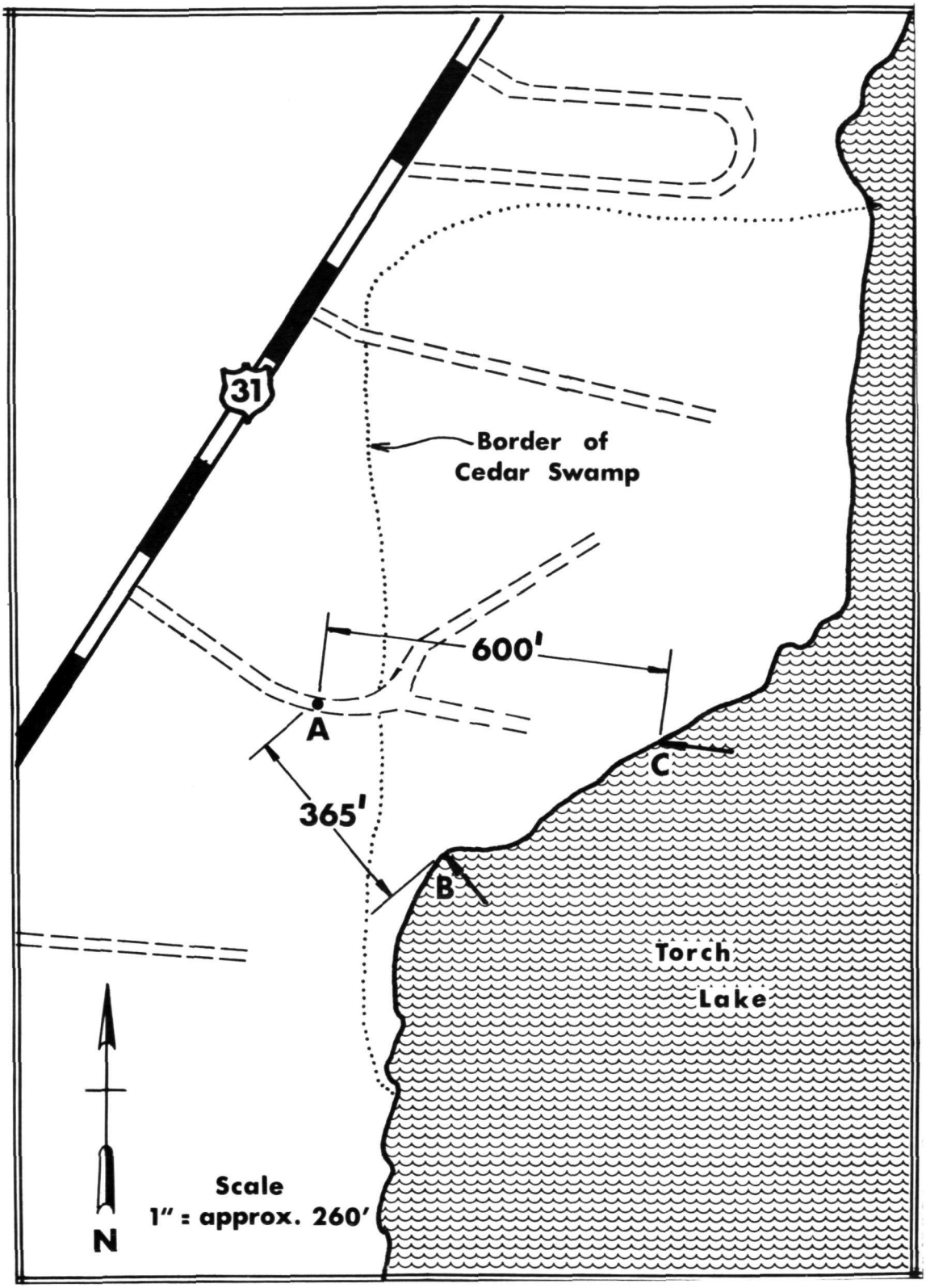


Figure 5. Site Location in Antrim County, Michigan.

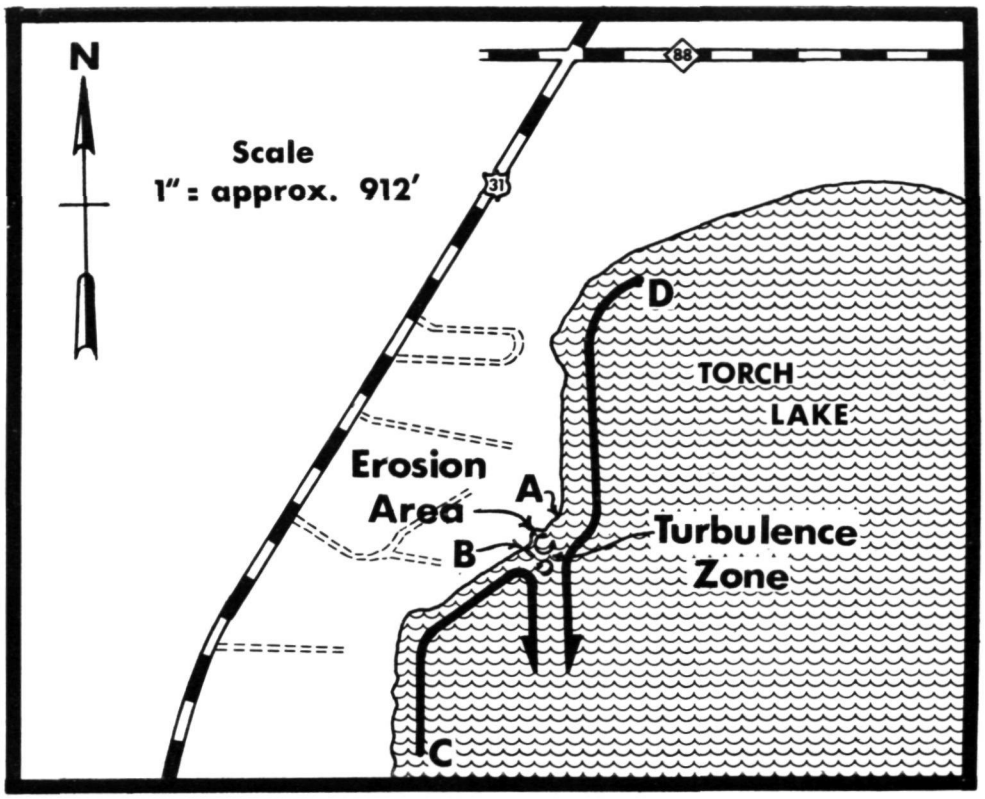


Figure 6.' Lake Current Dynamics
Torch Lake, Michigan

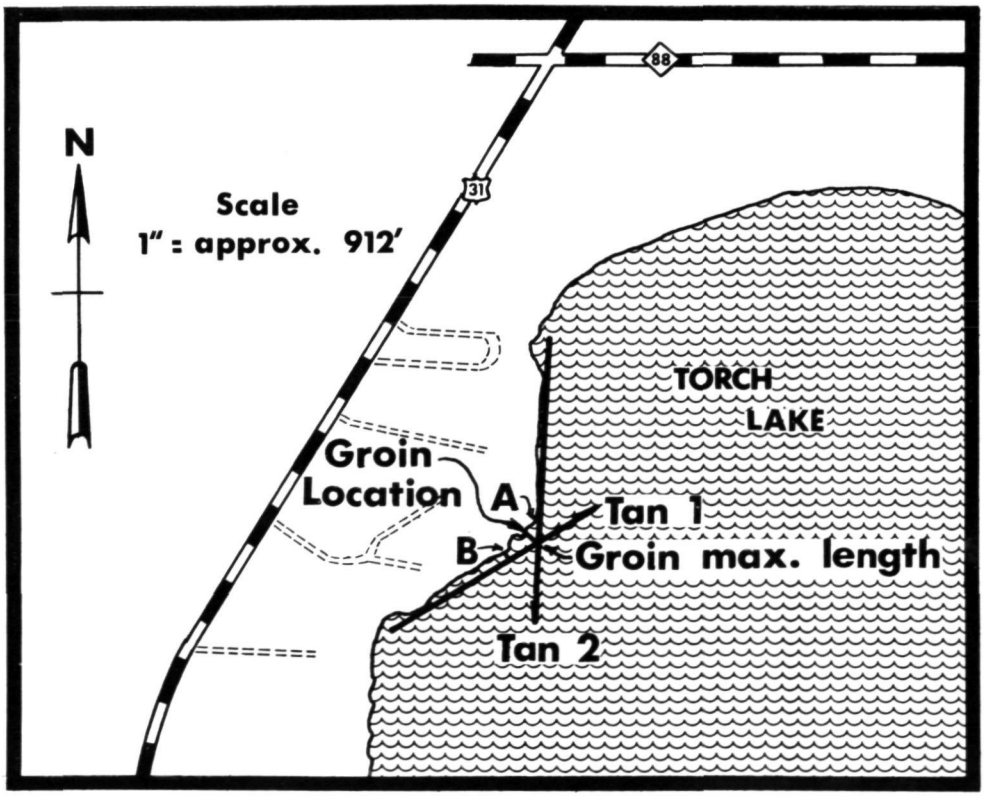


Figure 7. Determination of Groin Location and
Maximum Length

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DEVELOPMENT OF USER APPLICATIONS FOR EARTH RESOURCES SURVEY DATA IN URBAN AND REGIONAL PLANNING IN THE PUGET SOUND AREA

L-17

By Frank V. Westerlund, University of Washington, Seattle, Washington

ABSTRACT

User applications of remote sensing in Washington State are being developed by programs of the State Department of Natural Resources, the University of Washington, and the Pacific Northwest Regional Commission. The Remote Sensing Applications Laboratory of the University of Washington has been involved for three years in developing applications in urban and regional planning in the Puget Sound area through cooperative programs with governmental agencies.

Two such activities are described. The first project created a multi-temporal land use/land cover data base for the environs of the Seattle-Tacoma International Airport, to serve planning and management operations of the Port of Seattle. The second is an on-going effort to develop a capability within the Puget Sound Governmental Conference, a council of governments (COG), to inventory and monitor land use within its four-county jurisdiction. Developmental work has focused on refinement of land use/cover classification systems applicable at this regional scale and various levels of detail in relation to program requirements of the agency. Related research, refinement of manual methods, user training and approaches to technology transfer are discussed.

INTRODUCTION

Major centers of remote sensing applications activity in Washington State are the State Department of Natural Resources and the University of Washington. The Department of Natural Resources, through its Resource Inventory Section and State Remote Sensing Coordinator, utilizes both contract aerial photography, and LANDSAT and NASA aircraft imagery in inventory operations and research related to the Department's responsibilities for management of state lands. The Department also has an active mapping and orthophoto program. It provides information services and sale of aerial photography to the public and assists statewide users in the disciplines of forestry and agriculture.

At the University of Washington in Seattle, the Remote Sensing Applications Laboratory (UW-RSAL) of the Departments of Urban Planning and Geography has been involved during the last three years in developing applications among other user groups, particularly urban and regional planning agencies and other governmental units involved in land use or environmental planning. The vehicle for this development has been a series of cooperative programs with agencies at various jurisdictional levels from local (municipal) to state, with major emphasis on regional-level governments in the Puget Sound area such as large urban counties, councils of governments (COG's), and port authorities. Principal support has come from the Earth Resources Observation Systems (EROS) Program of the U.S. Department of the Interior, with aircraft data support from the Earth Resources Aircraft Program of NASA. Applications development at UW-RSAL has received and is continuing to receive direct support from the user agencies involved, including commitment of personnel time for training and participation in research, for purposes of technology transfer.

A third important activity which has recently come into being is a program of the Pacific Northwest Regional Commission, an organization composed of the governors of Washington, Oregon, and Idaho, funded by the U.S. Department of Commerce, and empowered to establish programs contributing to the economic development of the Pacific Northwest region. The Commission has established a Land Resource Inventory Task Force which has undertaken,

jointly with NASA Ames Research Laboratory and the U.S. Department of Interior EROS and Geography Programs, a two-year Land Resource Inventory Demonstration Project. The project will involve a group of disciplinary user teams from the three states in several phases of development, including definition of information needs, design of information products, experiments in digital and interactive image analysis, development of multi-purpose geographic information systems, user training, and planning for future development including programs and facilities for regionally based user assistance. A University Advisory Committee has been established to assist the Commission Task Force in this effort, and includes representation from the University of Washington.

In the context of these activities and programs, this paper describes two applications research efforts of UW-RSAL. Both involved user agencies in the Puget Sound area with operational responsibilities in urban and regional planning. Both projects were concerned with the establishment of land use/land cover data bases, and monitoring of change.

DESCRIPTION OF COOPERATIVE APPLICATIONS RESEARCH PROJECTS

Port of Seattle - Sea-Tac Airport Project

This study surveyed land surface cover and utilization in the vicinity of the Seattle-Tacoma International Airport, a major air transportation hub located in an unincorporated area of King County 13 miles south of the Seattle central business district. The airport is operated and managed by the Port of Seattle, a regional, special-purpose authority having rather broad powers for planning and capital programs related to ports, airports, and associated industrial development in the region; its powers include eminent domain.

Since initial airport construction during the period 1943-1948, the 130 sq. km. (50 square miles) surrounding the airport site have been transformed from a predominently rural area to an intensively built-up urban and suburban area with a population of 150,000. Residential and commercial development have encroached on all sides of the airport perimeter. Amid these circumstances, the airport environment has become a subject of pronounced concern and it appeared that a history of recent and long-term change in the character of the area as could be disclosed from aerial imagery might be basic to formulating policies to guide or regulate development. It was on this basis that the Port of Seattle supported the study.

Analyses aided by remote sensing data included several factors, such as:

1. How the airport site itself has developed, grown, and been modified since initial construction, 30 years ago.
2. How a major node of airport-related commercial activity has arisen adjacent to the airport, and continues to grow.
3. How the larger, surrounding area has developed, in part influenced by the airport, but also as a result of more general trends of metropolitan growth which have in certain respects conflicted with the airport.
4. How the surrounding transportation network has been altered by the airport.
5. Water quality problems produced by runoff from the large areas of impermeable surface on the airport site and adjacent commercial area; also sedimentation from exposed runway fills on the margins of the airport site, and its effect on creeks which drain the site westward into Puget Sound.
6. Specific instances of land use conflict, such as the location of schools and other institutional uses in relation to the airport approach pattern.
7. The relationship of superimposed noise contour data to observed land use in the vicinity of the airport.

The basic data collection supportive of these analyses took the form of a manually interpreted coextensive surface cover account on a 4.05 hectare (10-acre) cell basis for the approximately 48 square-mile sections of the Sea-Tac Community Planning Area, for the periods 1943, 1948, 1953, 1965, and 1972. The 10-acre unit of analysis, aligned to the Township and Range coordinate system, was chosen for consistency with data files of the Port and County based on 1/16 sections (16.2 hectares or 40 acres), which included noise monitoring data. Thus the surface cover information compiled from aircraft imagery was considerably more detailed than other data subsequently interfaced. It would have been preferable to use a metric cell unit aligned to the Universal Transverse Mercator (UTM) coordinate system, as this would have produced more accurate overall classification because of randomized cell placement in areas where parcel boundaries conform to the Township and Range system, however, in this case, the user's requirements were considered paramount.

A "two-digit" surface cover classification was used. This was developed in consultation with the Port, through modification of existing systems such as the Urban Renewal Administration - Bureau of Public Roads Standard Land Use Code[1] to produce a classification that: (1) emphasized surface cover categories rather than activities in depicting both urban and non-urban land use, (2) could be consistently applied at the two-digit level using high-altitude aircraft imagery, and (3) contained categories indicative of land utilization common or unique to the Puget Sound area. Development of land classification systems in relation to user needs and remote sensing capabilities is further discussed in the next section describing the Puget Sound Governmental Conference project.

An important technical aspect of the Sea-Tac work was the development of simple methods for constructing and registering grid overlays accurately scaled to each set of aerial photography. The 1972 data consisted of high-quality NASA color-infrared aircraft imagery at a scale of 1:50,000.[2] The historical coverage, all panchromatic black-and-white, varied considerably in quality; it consisted of contact prints and photomosaics at scales from 1:24,000 to 1:60,000. It was necessary to apply map control to all this photography by transferring section coordinates from 7-1/2' quad maps, transferring these points to scribe-coat material, mechanically interpolating cell boundary lines, and then making film positives from the scribe-coat sheets. The result was a set of grid overlays distorted to compensate for the distortions in each image (Fig. 1). Use of an optical transfer scope avoids the need for overlay construction since the grid can be constructed on the base map, and superimposition is automatic with image-to-map registery, however the above-described method may serve the needs of users lacking this or other photogrammetric equipment.

A standard display was developed to show the progression of surface cover change for each section over each time interval (Fig. 2). The five surface accounts are shown in the lefthand column; shaded cells have changed in surface cover since the previous time period. The histograms in the right column show the cellwise distribution of surface cover among the categories represented, which are ordered generally according to increasing intensity of land utilization, to reflect the progression of change in that direction. Note, in the section shown, that agricultural cover was supplanted by residential, which peaked about 1965, and has since been sacrificed to commercial, highway, and airport cover categories. These accounts have been computerized to interface with noise contour and other data.

A subsequent experiment indicated that LANDSAT-1 imagery could provide less detailed surface cover information at the 4-hectare (10-acre) level. With manual interpretation directly from separate-band imagery and diazo color composites this was limited to a relatively few cover types associated with features of high reflectance in all bands (e.g., bare soil, construction sites, quarries, extensive concrete especially where fresh, tracted residential with aggregate roofs, mobile home parks) and features of relatively low IR reflectance (e.g., asphaltic surfaces and water). It is apparent that these include many of the cover classes representative of recent and on-going change in the study area, and development at the urban fringe in general. High contrast of these features in color-IR with the prevailing forest vegetation of the Puget Sound area makes manual interpretation of LANDSAT imagery for purposes of change detection more practicable here than in some other environments.

Single-band level slicing of LANDSAT-1 MSS bands 5 and 7 using interactive display hardware at the University of California, Berkeley, improved the accuracy of these interpretations and made possible the detection of a sediment plume in Puget Sound adjacent to the airport, a water quality indication which was correlated with airport surface runoff.[3]

The Puget Sound Governmental Conference Project

The Puget Sound Governmental Conference (PSGC) is a regional council of governments (COG) in the central Puget Sound area, consisting of the counties of King, Snohomish, Pierce, and Kitsap, 29 constituent cities, and two Indian tribes. This four-county region contains the Seattle-Everett and Tacoma SMSA's, with a total population of two million people. Like COG's in other metropolitan areas, the role of PSGC is one of intergovernmental coordination for purposes of regional planning. Its influence lies chiefly in federal recognition of the Conference and its plans as a basis for "A-95" review of federal aid to local government in some 100 funding categories which include local planning, housing, transportation, airports, utilities, parks and recreation, health, law enforcement, and many others.[4] The Conference also reviews Environmental Impact Statements under the 1969 National Environmental Policy Act and the 1971 State Environmental Policy Act.

The basic policy tool supportive of this review process is a Regional Development Plan (RDP) which incorporates local and areawide goals, policies, and plans for the future development of the region. Preparation of the RDP is a lengthy process still in progress, while an interim plan guides present decision-making. The RDP will include many elements. Fundamental among these is a land use element incorporating plans of local government, but additionally defining relationships between land use and other functional elements of the RDP such as highways, transit, sewer, water, and specific land use allocations, so that the land use consequences of development policies can be ascertained. An Activity Allocation Model (AAM) will be used to allocate areawide forecasts of population and employment to subareas and translate these allocations into land use changes, thereby to assess the probable impact of regional policies on land use and urban growth.

An understanding of this background was necessary to begin to relate to this agency as a potential user of remote sensing data. Through discussion it became apparent that development of the RDP through implementation of AAM was impeded by the lack of adequate methods for inventorying present land use and for monitoring change. Although land use data exists in the building records and assessor's files of some 80 local governments, it is too disaggregated and varied in form to be practicably used or even accessed. An examination of the land use data requirements of the AAM in relation to prior work done at UW-RSAL such as the Sea-Tac project indicated that these needs could be met initially through manual interpretation of high-altitude aircraft imagery. Presentations to PSGC established the potential of this approach, and a cooperative agreement was reached for development of methodology, shared use of facilities and data, and training of PSGC personnel.

A pilot project was undertaken in Kitsap County, on the west side of Puget Sound. The smallest and least populated of the four counties, Kitsap was of special interest because of the anticipated impact of construction of the West Coast Trident Nuclear Submarine Base at Bangor, estimated to bring about 40,000 new residents into the area in the next few years. The objective of the pilot project was to compile a land use data base for Kitsap County which would be computerized and fully operational within the Activity Allocation Model, with the data derived from remote sensing interpretation carried out by the PSGC staff.

Probably the most important developmental aspect of this work was the design of a land use classification system fitting these purposes, based on user input, and suitable for manual — and later, machine-aided remote sensing interpretation. A number of weeks were devoted to the classification design process. The result is shown in Table I. Cursory examination of this classification system may not be revealing of the amount of thought that went into it, however, some of its attributes are as follows:

1. The system is fully compatible with and translatable to land use categories already defined in the Activity Allocation Model, which had been designed without

consideration of potential remote sensing input.

2. The system is largely compatible with, and reflects much of the thinking of the USGS Circular 671 classification system.[5] Like Circular 671, it incorporates both land use and land cover categories, i.e., land use is represented in terms of manifest cover types, along with natural cover. At the "one-digit" level, the PSGC-Kitsap system divides simply into "Undeveloped", meaning predominantly natural, plus agriculture, "Developed", meaning man-impacted, including all urban, "Construction", or transitional between the above categories, and "Military Lands", a necessary exclusion in this particular case. This breakdown reflected a program need to be able to call out the total urban service area for the county. The second-level breakdown is comparable in many respects to level one of Circular 671, except that it reflects a more urban bias in terms of a breakdown under "Developed" comparable in detail to the natural systems breakdown under "Undeveloped".

3. At all levels the system is particularly suited to remote sensing interpretation from various scales and types of input. Even at levels three and four, urban categories such as commercial area types are based on distinct spatial, and morphological characteristics (e.g., business districts, commercial strips, large and small nucleations, etc.) rather than traditional definitions of use related to activities, types of goods or services sold, etc. Although some planners are reluctant to adopt such new definitions, a strong arguement can be made that they relate better to actual considerations of environmental impact which are paramount in physical planning today.

In the pilot project interpretation was done from 1973 U-2 1:135,000 color-infrared imagery on an optical transfer scope, recording on frosted mylar overlays on a USGS 7-1/2' base.[6] Initial products included a level-two classification of the entire county, and a level-three classification of one quadrangle. The interpretation was recorded in polygons of two-hectare (5-acre) minimum size . An exercise was also conducted in intertemporal analysis, whereby an area was interpreted at level-three first from 1973 data and then from 1965 1:60,000 black-and-white photography. It was found that this could be done most effectively if the more recent interpretation was done first, utilizing the available CIR aircraft imagery, and then doing the interpretation for the earlier time period as another overlay on top of the first interpretation, and using pencil of a different color to do the delineation. For a developing area, this becomes a simple task of determining whether structures or other land uses in the "Developed" category already interpreted for the later date were present at the earlier date (and if so they are readily recognized); if not, it is a matter of removing and enlarging polygons as areas revert to adjacent "Undeveloped" categories.

Over a period of three months, five agency personnel, four of whom had no prior experience in photo interpretation, were brought to an operational level of capability in these techniques. Training also included ground truth verification procedures based on windshield transects of the study area.

The data from the initial work has been digitized and tested in the AAM. A preliminary decision has been made to change from a polygonal to a grid system utilizing a 2.23-hectare (5.5-acre) cell, partly determined by hardware and programming requirements of the AAM. Training exercises have been defined to extend manual interpretation abilities to include cellwise classification on the transfer scope, with emphasis on the decision processes involved in this type of data aggregation.

The next phase of the project is a translation of these techniques to digitally-processed LANDSAT data. PSGC is a designated user under the Pacific Northwest Regional Commission Land Inventory Demonstration Project mentioned in the Introduction, and the central Puget Sound area has been designated as the Washington State test site for users of the urban discipline team. PSGC personnel involved in the manual interpretation project are attending sessions at NASA-Ames and the EROS Data Center at Sioux Falls intended to familiarize them with the use of interactive hardware and automated spectral classification

procedures to determine how and to what extent these methods can now be applied to replicate or supplement an already established information collection process. The first such digital product, a supervised clustering of LANDSAT-1 data for the Bremerton area of Kitsap County has been compared with the manually derived information, and further refinement including aggregation to the 2.23-hectare (5.5-acre) cell unit is currently under development.

RELATED RESEARCH

As the foregoing has shown, a major emphasis of the research at UW-RSAL has been the improvement of manual techniques for the use of modern remote sensing image data products, particularly for purposes of land use/land cover classification. A related area of research is directed at achieving adequate levels of accuracy, consistency, and reproducibility of results in manual interpretation involving multiple interpreters over time.

Fig. 3 represents one type of consistency analysis, a graphic and numerical comparison of results obtained in two grid cell surface cover accounts of a sample area in central Seattle, a densely built-up residential, commercial and mixed-use area. In this example, two interpreters, A and B, made separate accounts from the same 1:120,000 color-infrared aircraft imagery using a 100-meter grid cell as the unit of analysis (400 data records for the 4 sq. km. sample area), with the grid aligned to UTM coordinates. These accounts appear at the bottom. The matrix shows the total number of cells classified according to a given two-digit code for each interpreter. The diagonal records the number of times a given classification used by Interpreter A was also used by Interpreter B. The off-diagonal row figures (for row i) represent the instances where Interpreter B made a different classification than i for cells classified i by Interpreter A, and the distribution of these different classifications.

In most comparisons of this kind it was found that the major part of the variability in classification away from the diagonal remains within the same general (one-digit) surface cover grouping, as shown at the top of the matrix. This type of analysis has been used to evaluate relationships between each of the several variables involved, e.g., experienced and inexperienced interpreters, sample areas of varying character, imagery of different types and scales, and variation in classification content and detail. The general finding has been that the level of consistency suggested by Fig. 3 is not unusual for surface cover accounting at the two-digit level from high-altitude aircraft imagery, given an appropriate cell size, and interpreters having had a few weeks of experience at this specific task, including ground verification experience.

A closely related problem is that of achieving as much objectivity as possible in interpretation — defining the way in which each category in the classification is applied and interpreted, and the way the data is aggregated in creating the primary information product, whether it be a delineation of polygons or an annotation of cells. For this purpose, much attention has been given to documentation of the interpretation process, including definition of the decision processes involved. The following is an excerpt of documentation developed for applying two level-three residential cover categories where a 4.05-hectare (10-acre) cell is used:

1. Single-family housing, tracted. Includes all areas of small-lot development, one-acre or less, in which lots are consecutively layed out and continuously or predominantly built-up over at least one-quarter of the cell area, i.e., 2.5 acres. If less than one-quarter of the cell is occupied by a housing tract, but more than one house, it would generally be classified as untracted (see 2, below)

   This category includes older, built-up residential sections of existing settlements as well as newer suburban tract developments. In most cases these are areas layed out and built under one plat, or a succession of plats, during a relatively short interval of time, however gradual in-filling to this defined density also results in this classification. In some areas the latter process is apparent, i.e., no

evidence of unified or systematic development.

2. Single-family housing, untracted. Pertains to less dense settlement — areas of rural-residential homesteads, farm or non-farm, larger than one acre. No maximum size is applied to such properties, nor should any attempt be made to interpret parcel boundaries. If two or more housing units appear in a cell under these density conditions, it should be given this classification. Under the one-acre lot criterion, ten or more houses in a 10-acre cell then require a tracted classification. (avg. lot $\leq$ 1 acre), unless four or more of these are contained in a tracted area occupying less than one-quarter of the cell area. In this case the number of houses in the cell can reach as high as 12 or 14 before the housing-tracted classification is applied, but such limiting cases are rare.

   The tracted versus untracted distinction is significant in terms of residential growth potential —"in-filling" can be expected to occur in untracted areas but not in tracted areas. Cell area, if used directly, is, of course, a very gross measure of residential area, particularly in the case of cells classified as housing-untracted. Streets, associated land not built upon, and small areas devoted to other land uses may be and usually are included. Cell measurement of total residential acreage will tend to be very large compared to any other method, this discrepancy varying with cell size, however cell measurement may represent fairly well the total land area committed to residential use.

   The exclusion of cells containing only one housing unit from any housing classification is a compensating factor for this exaggeration of residential area. Were such cells classified as housing, a great many additional cells would be involved, with effective loss of density discrimination and information pertaining to open space. The one disadvantage in not doing this is that the record is not complete as to occurrence of housing.

In the case of the PSGC project, this documentation is taking the form of a manual with illustrative examples of interpretation intended to help the agency in continuing application of these techniques.

A third area of related research is the development of simple but effective methods for interfacing information derived from remote sensing with data from other sources. An example of this was the combination of noise contour data with land use for the Sea-Tac Airport area. Both files of data were in a form permitting this to be done by computer, with tabular or alphanumeric output. In many cases a graphic superimposition is equally or more effective, since planners are accustomed to displaying information in map form. Therefore it was effective to show noise contours directly superimposed on the cellular data record, and, separately, on the imagery itself.

Two other studies which cannot be detailed here relied heavily on superimposition techniques, which we refer to as "visual modeling". One concerned a study done for Skagit County of secondary land use effects of a proposed nuclear power plant on the Skagit River; the other related to a study coordinated by the Oceanographic Commission of Washington of the feasibility of developing petroleum transfer facilities for Alaskan oil at alternative Puget Sound and coastal sites. In both studies the impact of urbanization attendant to these proposed developments was assessed in relation to available land resources at alternative locations through visual superimposition of projected development and growth patterns directly upon imagery and upon various thematic data extractions from imagery.

CONCLUSIONS

Some general conclusions drawn from this varied experience in developing user applications are as follows:

1. Mechanisms are needed for user assistance, training, and technology transfer, parti-

cularly in the field of urban and regional planning, where users typically have little or no experience with remote sensing and high initial resistance to its use. Organizations that can serve this function are universities and state agencies able to address a wide range of user disciplines at local and regional as well as state levels. Pooling of resources and specialties among a group of governmental and academic organizations in a state or multi-state region is one approach demonstrated by the Pacific Northwest Regional Commission program.

2. Such an organization or group of organizations must be able to work cooperatively with potential users to develop application relating to on-going problems and needs. They can provide initial contact with the remote sensing data itself, and access to necessary equipment and facilities. Also they can help users relate to NASA and other federal programs and sources of data. (For example, some 50 orders of data from the EROS Data Center originating from users in the Pacific Northwest have been assisted, and in many instances suggested or initiated by UW-RSAL. This kind of user assistance is probably common, but not evident in orders as received at EDC.)

   Of related importance are training programs. University short courses and workshops are one example. Special purpose training of an agency's personnel, as in the PSGC project, is another.

3. Many attempted applications still, and perhaps always will, require a certain amount of new, applied research. Hence the need for an on-going research function which can probably best be served by a university. Such research would be directed at specific, identified user needs, and undertaken in the context of an established relationship with a user. It is critically important that the users served be directly involved in the design and conduct of applied research related to attempted applications.

4. A principal area of such user design input is in the development or modification of land classification systems suitable for remote sensing data input, but which also serve the operational program needs of an agency. This is perhaps the most crucial of steps in utilization of remote sensing; whatever our concept of information is in relation to a problem, it is embodied in classification. Too often an existing or arbitrary classification system, or one dictated by requirements or limitations of hardware, software, or other tools to which an a priori commitment has been made, is adopted, without full realization that this is one of the most fertile areas for relating on specific terms to user needs and involving users.

5. There are many avenues of improvement and refinement in manual techniques which are worth developing, both for their own value and as a necessary background for intelligent design and application of machine methods. Photo interpretation from high-altitude aircraft and satellite imagery is different from that based on conventional aerial photography, incorporating new knowledge of pattern and spectral variation — visual knowledge which can be learned. Again, the design of classifications systems based on attainable capabilities of signature recognition as well as information needs is an essential link in demonstrating application. If this is accomplished first at a manual level, so that the essential nature of these relationships is understood, then the way is open for introducing users to the possibilities of machine assistance.

6. It is possible and practicable to train users in the planning field to do interpretation and use remote sensing data on their own. The idea that planners without prior experience will not learn to do photo interpretation is perhaps an initially gained impression, but our experience suggests that this can be overcome with persistence, and if an unmet information need exists. Whether long-term, continuing commitments of personnel and resources by agencies can be achieved remains to be seen, and will certainly depend upon convincing demonstrations of both broad applicability and cost effectiveness.

7. Because synthesis of information and analysis is a fundamental activity in the field of urban and regional planning, it is important that attention always be given to the way in which remote sensing derived information is subsequently used and combined or related to other information. Planning users are sometimes reluctant to accept remote sensing input because they cannot immediately visualize how it could be related to other material they employ. Deliberate design of interface media is required, of which visual or graphic superimposition can be one of the most effective. Successful combinations of data are, in a real sense, "more than the sum of parts," and can be persuasive demonstrations of the power of remote sensing as a tool of analysis; this is especially true where other data of a clearly vital nature are involved, and the combination permits an interpretation of that data which would not be possible without the contribution of remote sensing.

ACKNOWLEDGEMENTS

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REFERENCES

1. U.S. Urban Renewal Administration and U.S. Bureau of Public Roads, Standard Land Use Coding Manual, A Standard System for Identifying and Coding land Use Activities, Washington: U.S. Government Printing Office, 1965.

2. NASA Johnson Space Center Mission 212, SRT Project 135, Test Site 286 - Washington State Regional, September 4, 1972, P-3A aircraft, RC-8 camera, film type 2443, image scale 1:50,000.

   Historical aerial photography for 1943 was acquired from the Defence Mapping Agency, Ft. Belvoir, Virginia, with the assistance of the EROS Program. Historical coverage for 1948, 1953, and 1965 was acquired from Walker and Associates, Seattle.

3. LANDSAT-1, July 29, 1972, #E-1006-18313 (Seattle-Tacoma scene), MSS bands 5 and 7.

   Processing of this imagery was done at the Space Sciences Laboratory of the University of California, Berkeley, whose assistance is gratefully acknowledged.

4. U.S. Office of Management and Budget Circular A-95, which implements the Intergovernmental Coordination Act of 1968 by mandating state and regional level reviews of federal aid applications.

5. U.S. Geological Survey, Circular Series No. 671, A Land Use Classification System for Use with Remote Sensor Data, prepared by James T. Anderson, Ernest E. Hardy, and John T. Roach, Washington: U.S. Government Printing Office, 1972.

6. NASA Ames Research Center Flight 73-109, July 3, 1973, U-2 aircraft, RC-10 camera, film type 2443, image scale 1:135,000.

TABLE I.

LAND USE CODING KEY - REMOTE SENSING PROJECT FOR KITSAP COUNTY

1.	UNDEVELOPED
1.1.	Water
1.1.1.	Saltwater (marine)
1.1.1.1.	Estuarine waters
1.1.2.	Lakes, ponds
1.1.3.	Reservoirs, impoundments (non-utility oriented)
1.1.4.	Rivers, streams (primary channel or streamway)
1.1.4.1.	Sloughs, side channels
1.1.4.2.	Bars
1.1.4.3.	Islands
1.2.	Shorelands
1.2.1.	Beaches
1.2.1.1.	Spits
1.2.1.2.	Barrier bars
1.2.2.	Bluff
1.2.2.1.	Head land
1.2.3.	Inter-tidal mudflats
1.2.3.1.	Estuarine mudflats
1.3.	Wetlands
1.3.1.	Emergent vegetation
1.3.2.	Marsh
1.3.2.1.	Freshwater
1.3.2.2.	Saltwater
1.3.3.	Estuarine Wetland
1.3.4.	Bogs
1.3.5.	Brush swamps
1.3.6.	Swamps
1.3.7.	Areas subject to periodic ponding or inundation
1.4.	Forested open space
1.4.1	Cut lands (0-20 years)
1.4.1.1.	Clear-cut
1.4.1.2.	Selected
1.4.2.	Second growth forest
1.4.2.1	Deciduous (broad leaf, hardwood)
1.4.2.2.	Mixed
1.4.2.3.	Coniferous
1.4.3.	Old growth
1.4.4.	Unique forest vegetation
1.4.5.	Riparian vegetation
1.5.	Non-forested open space
1.5.1.	disturbed vegetation
1.5.1.1.	Grassy (herbacious)
1.5.1.2.	Brush
1.5.2.	Meadows
1.5.3.	Rock lands
1.5.4.	Talus slopes
1.5.5.	Glaciers

TABLE I. (Cont'd)

1.6.	Agriculture
1.6.1.	Crop land
1.6.2.	Orchard
1.6.3.	Pasture
1.6.4.	Tree farms
2.	DEVELOPED
2.1.	Residential
2.1.1.	Untracted single family
2.1.2.	Tracted single family
2.1.3.	Multi-family
2.1.4.	Mobile home courts
2.2.	Commercial
2.2.1.	Business districts
2.2.1.1.	Central business districts
2.2.1.2.	Neighborhood/community business districts
2.2.2.	Commercial strips
2.2.3.	Shopping centers
2.2.3.1.	Regional shopping centers
2.2.3.2.	Community shopping centers
2.2.4.	Large isolated retail
2.2.5.	Small nucleations (2 to 6 retail establishments)
2.3.	Wholesale commercial/light industry
2.3.1.	Wholesale commercial, warehousing, light industry
2.3.2	Light industry or office parks
2.3.3.	Wrecking yards
2.4.	Industrial, manufacturing
2.4.1.	Food and kindred products
2.4.2.	Lumber and wood products
2.4.3.	Pulp and paper products
2.4.4.	Oil and chemical products
2.4.5.	Metal processing
2.4.6.	Stone and concrete products
2.4.7.	Transportation equipment
2.4.9.	Other
2.5.	Transportation
2.5.1.	Major highway R.O.W.
2.5.2.	Major rail R.O.W.,railyards
2.5.3.	Rail terminal facilities, shops (intensive use)
2.5.4.	Motor transport terminals
2.5.5.	Bus terminals
2.5.6.	Ports
2.5.7.	Ferry terminals
2.5.8.	Airports
2.5.8.1.	Commercial air transport
2.5.8.2.	General aviation

TABLE I. (Cont'd)

2.6.	Utilities and communications
2.6.1.	Communications
2.6.1.1	Intensive
2.6.1.2.	Extensive
2.6.2.	Utilities
2.6.2.1.	Intensive
2.6.2.1.1.	Water Supply/treatment
2.6.2.1.2.	Reservoir structure
2.6.2.1.3.	Sewage treatment plants (including lagoons and settling ponds)
2.6.2.1.4.	Power plants, stations
2.6.2.2.	Extensive
2.6.2.2.1.	Water supply system (aqueducts, pipelines, canals)
2.6.2.2.2.	Power transmission ROWs
2.6.2.2.3.	Pipelines (oil, gas)
2.7.	Institutional
2.7.1.	Government
2.7.2.	Schools
2.7.3.	Hospitals
2.7.9	Other
2.8.	Parks and recreation
2.8.1.	Intensive recreation, amusement (stadiums, zoos, race tracks)
2.8.2.	Golf courses
2.8.3.	Parks
2.8.3.1.	Municipal
2.8.3.2.	County
2.8.3.3.	State
2.8.4.	Cemetaries
2.8.5.	Marinas
2.9	Mining and landfill
2.9.1.	Sand and gravel
2.9.2.	Coal
2.9.9.	Landfill, improvement
3.0.	CONSTRUCTION (transitional)
4.0.	MILITARY LANDS

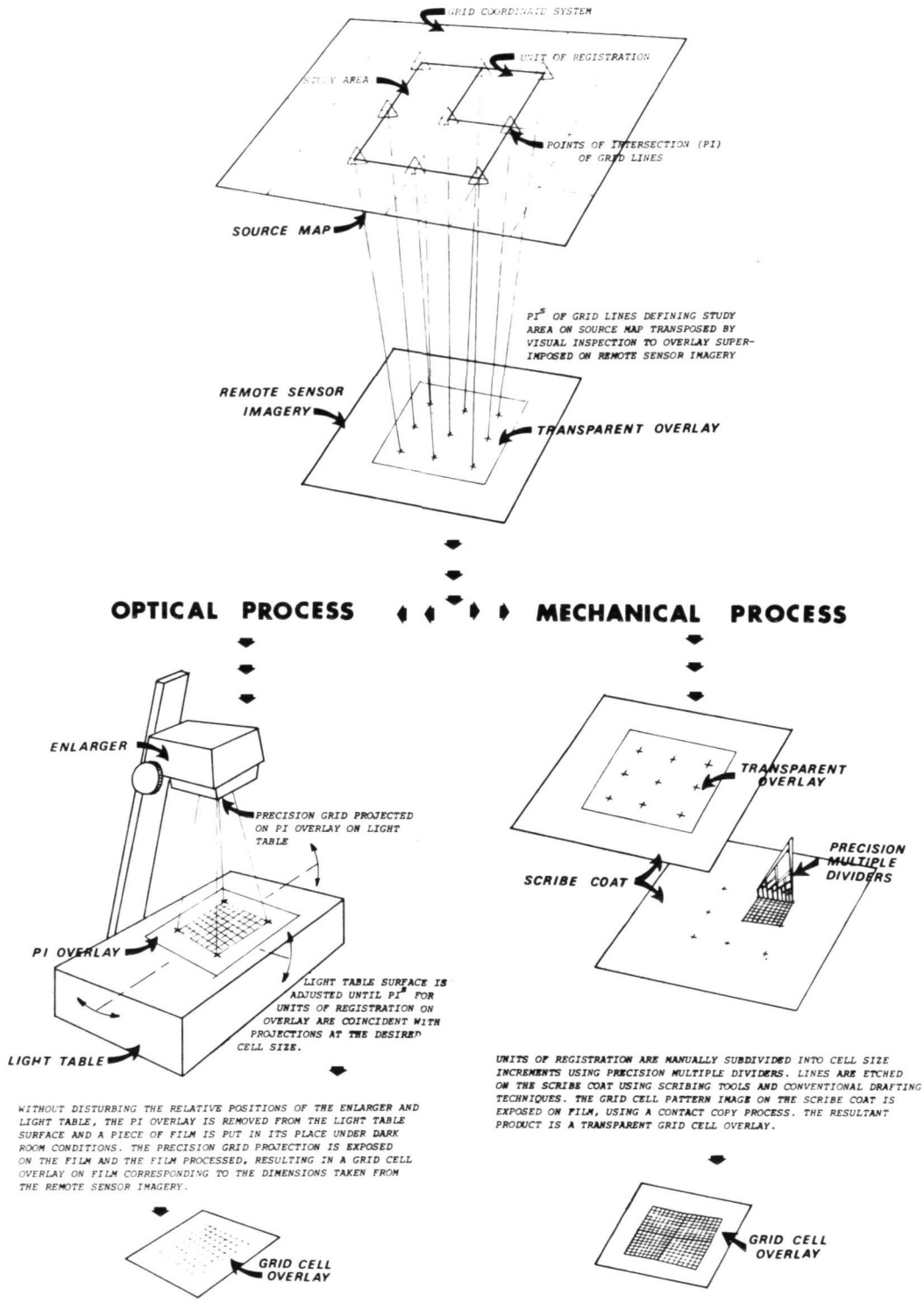


Figure 1.- Grid cell alignment on imagery, and development of grid overlay.

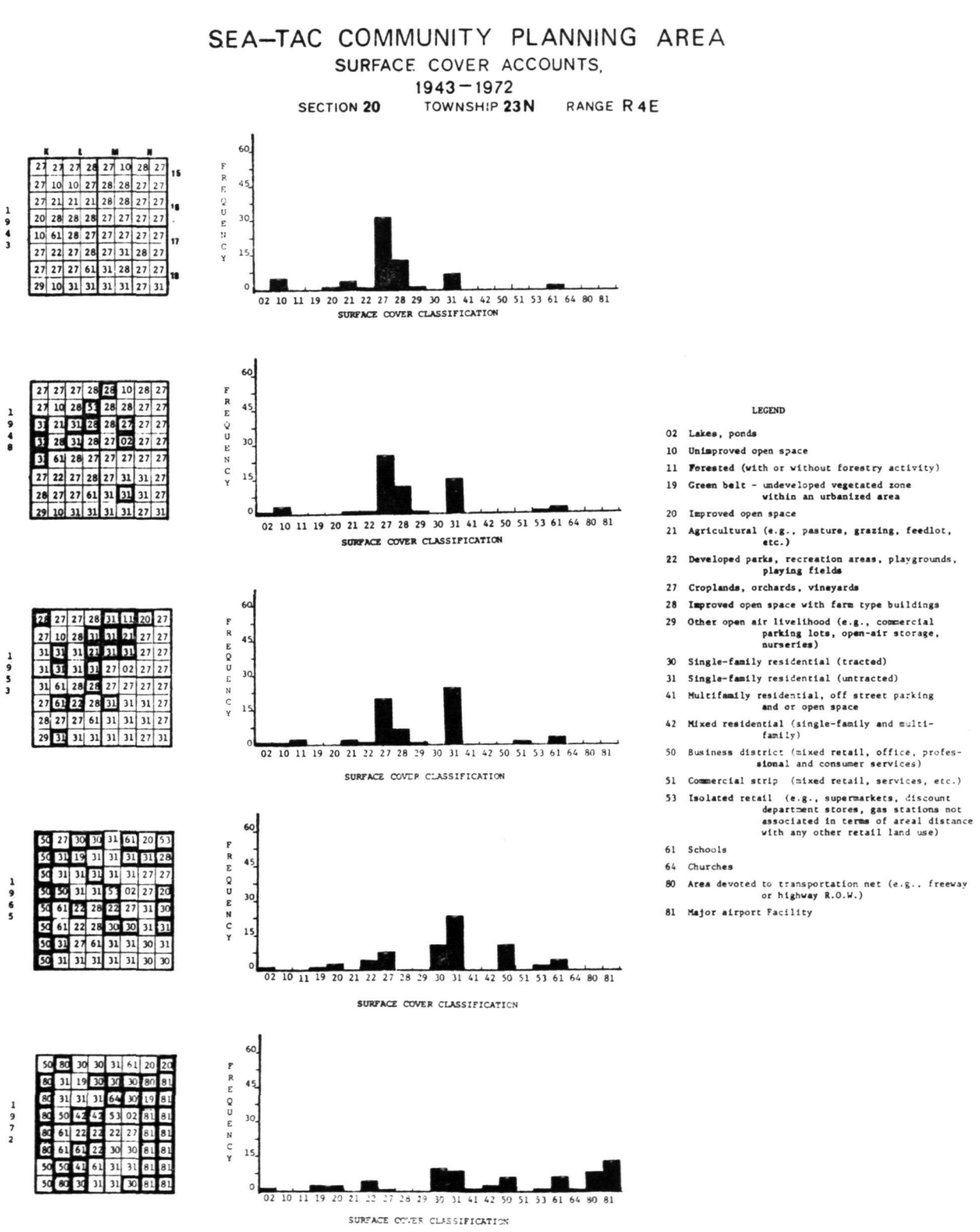
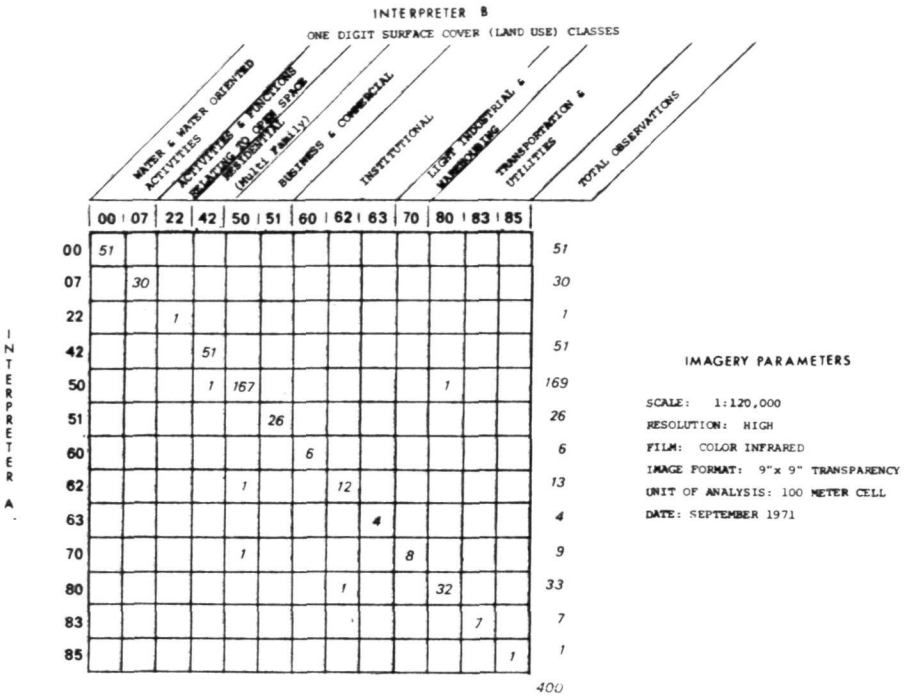


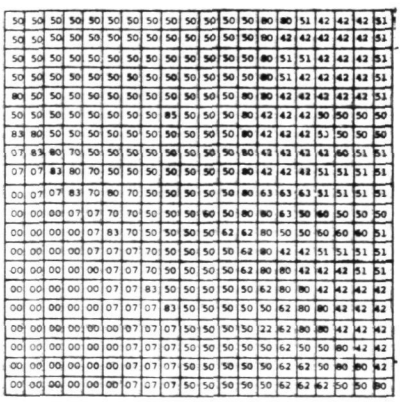
Figure 2.- Display of surface cover distribution for one section, for five time periods.



IMAGERY PARAMETERS

SCALE: 1:120,000
RESOLUTION: HIGH
FILM: COLOR INFRARED
IMAGE FORMAT: 9"x 9" TRANSPARENCY
UNIT OF ANALYSIS: 100 METER CELL
DATE: SEPTEMBER 1971

INTERPRETER A



INTERPRETER B

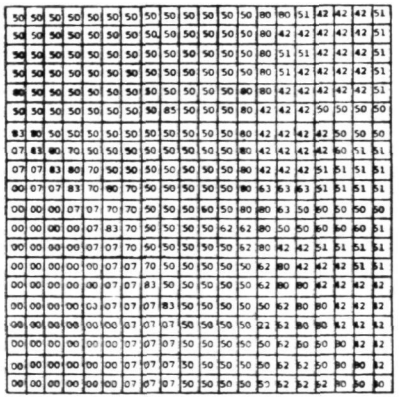


Figure 3.- A comparison of surface cover accounts for a sample area by two different interpreters: a measure of consistency in manual interpretation of surface cover.

APPLICATION OF SATELLITE REMOTE-SENSING DATA TO LAND SELECTION AND MANAGEMENT

L-18

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ABSTRACT

The Alaskan regional Native corporations currently are engaged in the selection of land entitlements authorized in the Alaska Native Claims Settlement Act by the U.S. Congress in 1971. The areas of the public domain reserved for selection by native groups are vast and remote, and the time available for land selection tends to rule out land-use planning done by conventional means. Doyon, Ltd. of central Alaska is one of the regional corporations which faces such a massive resource management challenge. With Bureau of Indian Affairs and NASA funds, the University of Alaska undertook a pilot project to demonstrate the utility and economy of satellite data in preparing thematic maps of a wilderness area emphasizing those resources of greatest interest to the potential owner.

Vegetation maps delineating potential commercial timber and maps of suggested mineral prospecting areas of seven scattered regions were prepared by interpretation of LANDSAT images, coupled with a limited amount of ground truth. Images acquired both in winter and summer seasons were registered to township maps and used in making interpretations of the areal extent of commercial timber potentials. The amount of snow cover visible through the forest canopies was found to be a useful indicator of timber potentials. No attempt was made to estimate timber volume. The satellite images were also interpreted to identify the nature of bedrock where this was possible. Identification was also made of characteristic topographic features which are typical of flood plain deposits or of the well-developed trellis drainage patterns which can indicate the strike of structural grain of underlying Cretaceous sedimentary rocks. The presence of igneous and mixed igneous and metamorphic rocks were indicated by combinations of spectral differences and anomalous interruptions of local radial drainage patterns.

Based in part on these newly-generated resource inventories of some 8,500 square miles, Doyon, Ltd, is now making land selection decisions. For example, Doyon has petitioned the Secretary of the Interior for a change in one boundary of a native regional deficiency withdrawal area to better accommodate the mix of resources of prime interest to this native group.

Verification of the vegetation interpretation of satellite data was performed on a spot basis by inspection from low altitude aircraft. Good conformity was found between the timber maps prepared from the satellite images and the selected test areas. The scope of work did not permit quantitative measurement on a statistical basis of the classification accuracy.

INTRODUCTION

Currently the Alaskan regional Native corporations and village councils are engaged in selection of lands authorized by the Alaska Native Land Claims Settlement Act. The work reported here was performed as a result of a request by Doyon, Ltd., a regional corporation of interior Alaskan Natives, for assist-

ance in obtaining resource materials and in training their personnel for this process of land selection and the management of lands selected.

The Geophysical Institute, with support from the Bureau of Indian Affairs, U.S. Department of the Interior, agreed to generate thematic maps from remote-sensing data analysis to aid Doyon, Ltd. in their selection process. This project was conceived as a pilot program of resource surveys designed to assist Alaskan Native corporations and villages in the process of land selection and management after selection.

One goal of this project was to demonstrate the utility of LANDSAT data for land use analysis in Alaska in view of the general lack of resource data - particularly vegetation and land use maps - throughout Alaska. The University of Alaska has been a major participant in the LANDSAT program, and as a result of this activity, has brought scientists together from geology, ecology, forestry, mineral engineering, wildlife management, hydrology, meteorology, agriculture, and the marine sciences to develop methods for applying remotely sensed data to regional land use surveys in Alaska.

It is believed that many of the techniques and approaches which have been developed can be utilized directly by regional and village corporations in the process of making land use decisions. This report illustrates those techniques and provides guidelines which can be applied to other regional corporations, village corporations, state and regional governmental agencies facing similar land use decisions.

PRODUCT PREPARATION

All existing Alaskan resource data, including the recently acquired LANDSAT data, was used to provide a resource base for land use maps and/or prospecting area maps of 250 townships considered to be of high priority for selection decision by Doyon, Ltd. In addition, township and range data were projected onto 1:250,000 scale LANDSAT images to aid direct use of the imagery for land use decisions.

Prospecting Area Maps

The objective of the mineralization analysis was to delineate areas for which interpretation of LANDSAT images, combined with existing ground and aerial data, indicated a favorable probability of metallic or non-metallic mineral products. It should be emphasized that the object of this analysis was not to pinpoint mineral deposits on the basis of LANDSAT data. However, interpretation of LANDSAT data in conjunction with other available geophysical data, including the distribution and characterists of known ore deposits, was used to define areas where <u>further prospecting</u> is warranted.

The importance of this type of information to the user must be clearly recognized. The size of the areas under investigation was so great that the cost of doing a rapid reconnaissance for identification of favorable prospecting areas by any other means would be prohibitive. This was particularly true in view of the time frame within which the land selections must be completed.

The basic procedures in a prospecting area analysis are:

(1) Assemble and organize all geophysical data relating to the likelihood of ore deposits in the area under study. These data are organized to indicate the distribution of potential mineralization regions of similar types and the nature of the geological control prevailing in each region.

(2) Prepare maps of mining districts, known mining claims and other relevant data and locate these on LANDSAT images.

(3) Interpret the LANDSAT data to identify distinctive features of the geologic environment, land forms, vegetation, and tectonic faults which can be associated with each potential mineralized province, and determine which combination of these features might justify extending the boundaries of known mining districts or projecting the trends of known deposits into new areas.

(4) Prepare maps of the study area indicating locations of favorable prospecting areas.

As previously noted, this process does not immediately pinpoint ore deposits. However, it is believed to have served the land selection requirements of the regional corporation effectively, because those requirements called for a selection by Doyon of approximately one-third of the lands held available for settlement purposes. Hence, all that was required was the determination of mineralized areas suitable for further prospecting. All these areas, comprising less than one-third of the land available for selection could be selected leaving the possibility of selection of other lands for yet other purposes.

Land Use Maps

Land use maps of Alaskan areas are of increasing importance with the current rush into land disposition and resource exploitation. Such maps provide a spatial basis for a resource inventory as well as a possible basis for a quantitative inventory of selected resources. Thus they serve as an effective tool in the land selection process. Land use maps may help in organizing activities compatible with a natural environmental integrity and hence with regeneration potentials, esthetic qualities and the rational, long-range needs of the exploiter.

The land use maps prepared as part of this project are essentially vegetation maps depicting broadly-defined vegetation types at the scale of 1:250,000. Although botanically coarse and of small scale, these maps provide more information, especially spatial, than any previous maps of the areas and are a step toward the production of more meaningful land use maps in Alaska.

The basic procedures in preparation of the land use maps were as follows: The maps were drawn from LANDSAT images. The reasons for this were (1) LANDSAT image availability, (2) the usefulness of LANDSAT imagery for mapping broadly-defined vegetation types over large areas in a relatively short time and (3) lack of complete aerial photograph coverage. LANDSAT images used for mapping were 16"x20" photographically enlarged prints produced at a scale of 1:250,000. The land use nomenclature adopted for this map series is a system developed by James R. Anderson of the U. S. Geological Survey.

Some of the scenes, were obtained by the satellite in the late winter, when the landscape was generally snow-covered, but when plants taller than the snow pack were free of snow. In the forest zone of interior Alaska snow accumulation by late winter usually is about one meter, after taking into account for recrystallization and compaction. Further snowfall in late winter is normally infrequent and light. These scenes permitted estimations of vegetation structure based on gray scale continuum related to plant height and cover.

Other scenes, obtained in the summer, were printed in color infrared. These permitted several coarse floristic distinctions based on some knowledge of the infrared reflectance of high-cover species or groups of species.

Information from the winter and summer images overlaid together was used in making vegetation distinctions to the extent that they may be expressed by the classification system that was adopted. Interpretations were also based on physiographic information obtained from topographic maps, as there are general relationships between vegetation and physiography.

The identification of vegetation containing trees of possible commercial grade of timber first required the identification of forest vegetation, then an estimation of composition and stature using the kinds of spectral and physiographic information described above. A quantitative definition of commercial timber was not intended. The commercial stands depicted on the maps are those in which the occurrence of a number of larger trees suitable for lumber production appears likely. This extension of vegetation-type classification to include possible commercial timber was performed because other than mineralization, timber resources represent a major possible consideration for the land selection decisions of Doyon, Ltd.

The materials prepared for the Kaltag selection area in western Alaska along the Yukon River will illustrate the kinds of thematic maps produced from LANDSAT images.

LANDSAT image 1038-21301 shown in Figure 1 illustrates the northern half of this selection area. This area is relatively remote, even by Alaskan standards. There are no settlements along the Yukon for nearly 140 km south of Kaltag. There are no roads to or within the area nor are there any airfields. The only transportation available is by barge along the Yukon River during the summer. The only known mineral extraction within the area occurred early in this century when two small coal deposits located on the river bank were mined. Logging, was limited to production of cord wood for steamboats. Today it appears that the mineral potential is still largely unexplored and many fine stands of commercial-sized spruce and hardwoods are found within the area.

DATA PRODUCTS

Figure 2 shows the map of possible prospecting areas prepared from the results of this study. After a review of the scant geologic literature available, the areas were identified in which the surface rocks are dominantly igneous or metamorphic, because these are most likely to contain deposits of metallic minerals. The character of these areas, in terms of topography and extent of outcrop, was determined from the study of available maps, LANDSAT imagery and observations during a light aircraft flight over the entire withdrawl area. The recommendations based on this analysis were as follows:

1. Areas covered by flood plain (the dotted area) on the other alluvial deposits were delineated on the LANDSAT imagery and were removed from further consideration because of the great expense of determining the nature of the underlying bedrock.

2. Areas where the surface rocks are cretaceous sedimentary rocks (identifiable on LANDSAT images by their characteristic of trellis drainage pattern of weathered sedimentary rocks) are shown with horizontal stippling. These rock types have low potential for mineralization and mineral exploration. These areas were not recommended for mineral exploration despite the existence of coal deposits which are of apparent limited extent.

3. The region of mixed sedimentary and igneous rocks, shown with left-stippling would have been a candidate for prospecting. However, a geological reconnaissance had been performed in that area with negative results.

4. The Blackburn Hills are largely granitic rocks, and are shown with vertical stippling. It appears to contain a granitic pluton and possibly radial dikes. We recommend that this area be prospected by stream sampling techniques.

5. A topographic dome structure located in the Kaiyuh Mountains contains one of the few known prospects in the withdrawl area and has been denoted by cross-hatched stippling. The prospect is located on a hilltop with shallow overburden and yielded molybdenum sulfide minerals in a quartz vein associated with a rhyolite porphyry. We suggested that this area be prospected for the possibility of low grade copper and molybdenum ores often associated with these types of rocks.

6. An area consisting of the Kaiyuh Mountains, and their topographic extension to the southwest is shown as right-stippling and was designated as an area for low-density prospecting. The mixture of igneous and metamorphic rocks of the Kaiyuh Mountains extends to the southwest as identified by the irregular drainage pattern indicative of this rock type.

Figure 3 is the land-use map of the Kaltag withdrawal area delineating eight major ecological communities. Of these, three were differentiated in terms of the apparent potential for marketability of hardwoods and softwoods based upon tree size alone. This distinction was denoted with a "C" classification signifying "potentially commercial" forests. However, a true commercial classification would depend on many factors far beyond the scope of this analysis.

The areas containing chiefly large-sized trees are denoted by cross-hatched stippling. Distinction has been made between broad-leaved forests containing chiefly birch (Betula papyrifera), aspen (Populus tremuloides), and balsam poplar (Populus balsamfera) as categories 41 and 41C; needle-leaved forests consisting of white spruce (Picea glauca) and black spruce (Picea mariana) as categories 42 and 42C; and mixed forests as categories 43 and 43C.

One of the goals of the regional corporation was to map the forests that have commercial timber potential to aid in their decision-making process of land selections. Generally we extended our analyses well beyond the boundaries of the withdrawal area, particularly where it was apparent that a forest or mineralized zone exceeded the extent of the area available for selection. Figure 4 is a third map showing the areas of potentially commercial timber (horizontal stippling) and areas for further prospecting (vertical stippling).

This map is useful from several points of view. The regional corporation was still in the process of negotiating with the federal government for changes in the withdrawal boundaries. The corporation could, for instance, negotiate for an entire forested area instead of an uneconomical portion of a potentially commercial forest.

Owing to an early deadline for land selections the map also supports selection decisions without the requirement of extensive field surveys. The Native Corporation may select only one out of three acres contained in the withdrawal area, and in the Kaltag area two-thirds of the land available for selection has no potential for forest products for easily identifiable mineral deposits. In this instance, the land selection process can be based completely upon the interpretation of LANDSAT image analyses.

Finally, by using these maps the directors of the corporation could make strategic decisions concerning the allocation of exploratory resources during the limited time available for preliminary surveys.

SUMMARY

LANDSAT imagery has been applied in central Alaska to earth resources management activities of a Native regional corporation in central Alaska which is entitled to select one-third of the land in a withdrawal area designated for this purpose from the public domain. Although the application of LANDSAT data was extended to 250 townships, only those 47 townships involved in the Kaltag withdrawal area are reported in this paper. They are illustrative of the methods used throughout seven regions in the interior Alaska which are subjects of Native land selection processes.

Thematic maps delineating highly probable areas for commercial timber and for mineral exploration were developed from satellite images using photo interpretation techniques coupled with a very limited amount of ground truth and correlation with geologic reports. These maps, which constitute a new, type-specified resource inventory, have been used by Doyon, Ltd. in making land-selection decisions. These resource inventories have proven to be exceptionally cost-beneficial and timely to generate, largely owing to the synoptic scope and ready availability of LANDSAT data.

Some 2 million acres have been selected as part of the land entitlement of Doyon, Ltd., and these selections were based heavily upon the thematic maps produced from analysis and interpretation of LANDSAT data. The value of these lands can be estimated in the range from $20 million to $200 million. A most conservative assumption is that the application of LANDSAT data at least doubled the value of the land selected in comparison with the land not selected. The benefits of this application can range between $10 million and $100 million, although this can not be defined precisely. This means that the benefits exceed the cost of the application of LANDSAT data by a factor ranging from 250:1 to 2,500:1, not taking into account the cost of development and deployment of the spacecraft or the cost of acquisition and dissemination of the data from the spacecraft.

This work was supported by USDI/Bureau of Indian Affairs contract EOOC14201079 and NASA grant NGL 02-001-092 from the Office of University Affairs.

BIBLIOGRAPHY

Anderson, J.R., et al. A land-use classification system for use with remote-sensor data, Geological Survey Circular 671, 1972.

Anderson J. H., et al. Vegetative and Geologic Mapping of Western Seward Peninsula, Alaska, based on ERTS-1 Imagery. Proceedings of Symposium on Significant Results Obtained from the Earth Resources Technology Satellite, Vol. I, pp. 67-75, NASA/GSFC, 1973.

Barnes, F.F., Coal resources of Alaska: U.S. Geological Survey Bull. 1242-13, p. 13, p. 131-137, 1967.

Cass, J.T., Reconnaissance Geologic Map of the Norton Bay Quadrangle, Alaska: U. S. Geological Survey Misc., Geol. Inv. Map I-286, 1959.

Cass, J. T., Reconnaissance Geologic Map of the Norton Bay Quadrangle, Alaska: U. S. Geological Survey Misc. Geol. Inv. Map I-288, 1959.

Cass, J.T., Reconnaissance Geologic Map of the Norton Bay Quadrangle, Alaska: U.S. Geological Survey Misc. Geol. Inv. Map I-291, 1959.

Cobb, E.H., Metallic mineral resources of nine Alaskan quadrangles: U.S. Geological Survey Open-file report, 1968.

Mertie, J.B., Jr., The Kaiyuh Hills, Alaska: U.S. Geological Survey Bulletin 868-D, P. 145-178, 1937.

West, W.S., Reconnaissance for radioactive deposits in the lower Yukon-Kuskokwim region, Alaska: U.S. Geological Survey Circular 328, 1954.

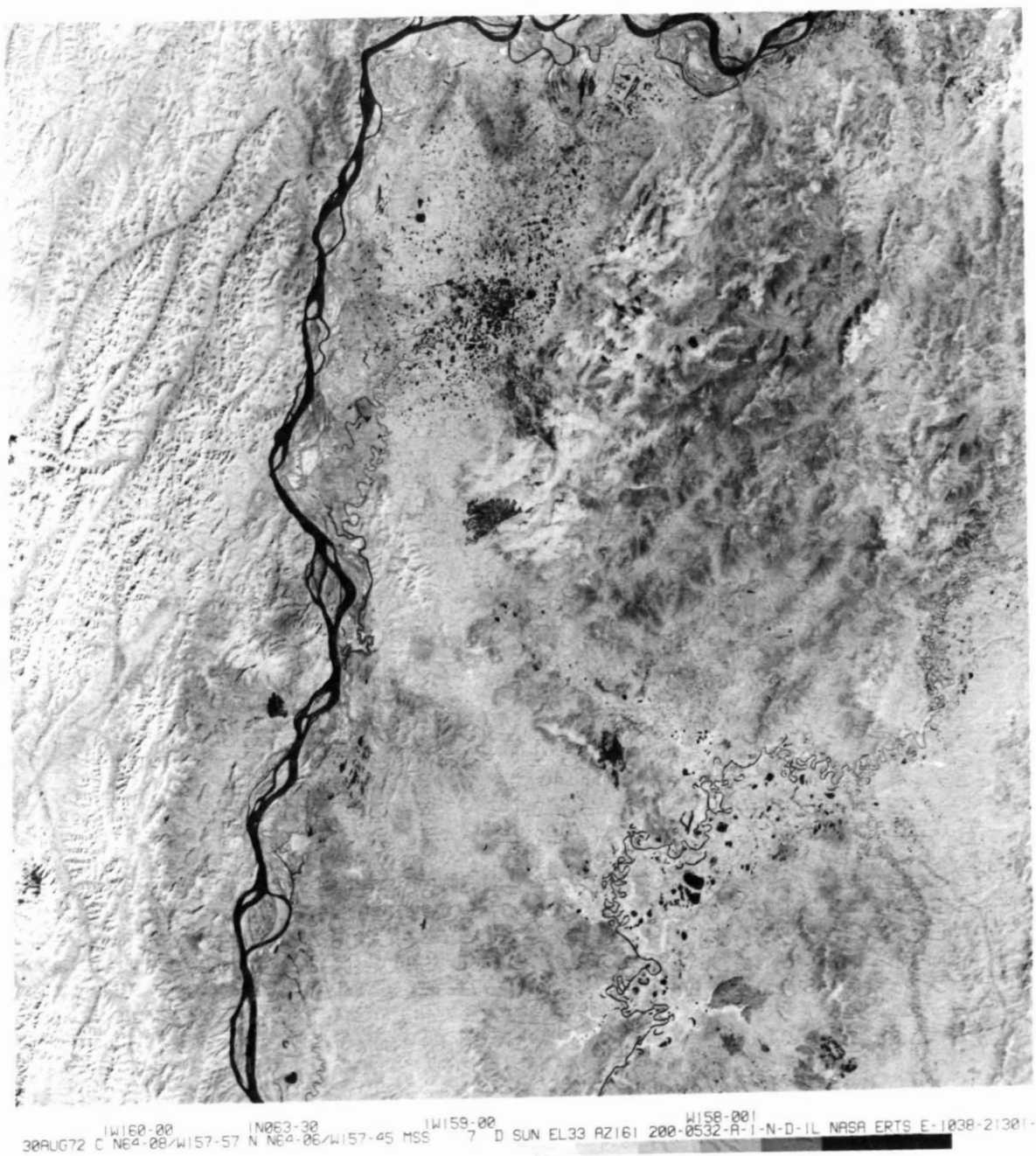


Figure 1. LANDSAT image of a portion of the Kaltag withdrawal area. A resource inventory of this remote region was prepared for land selections by a Native group.

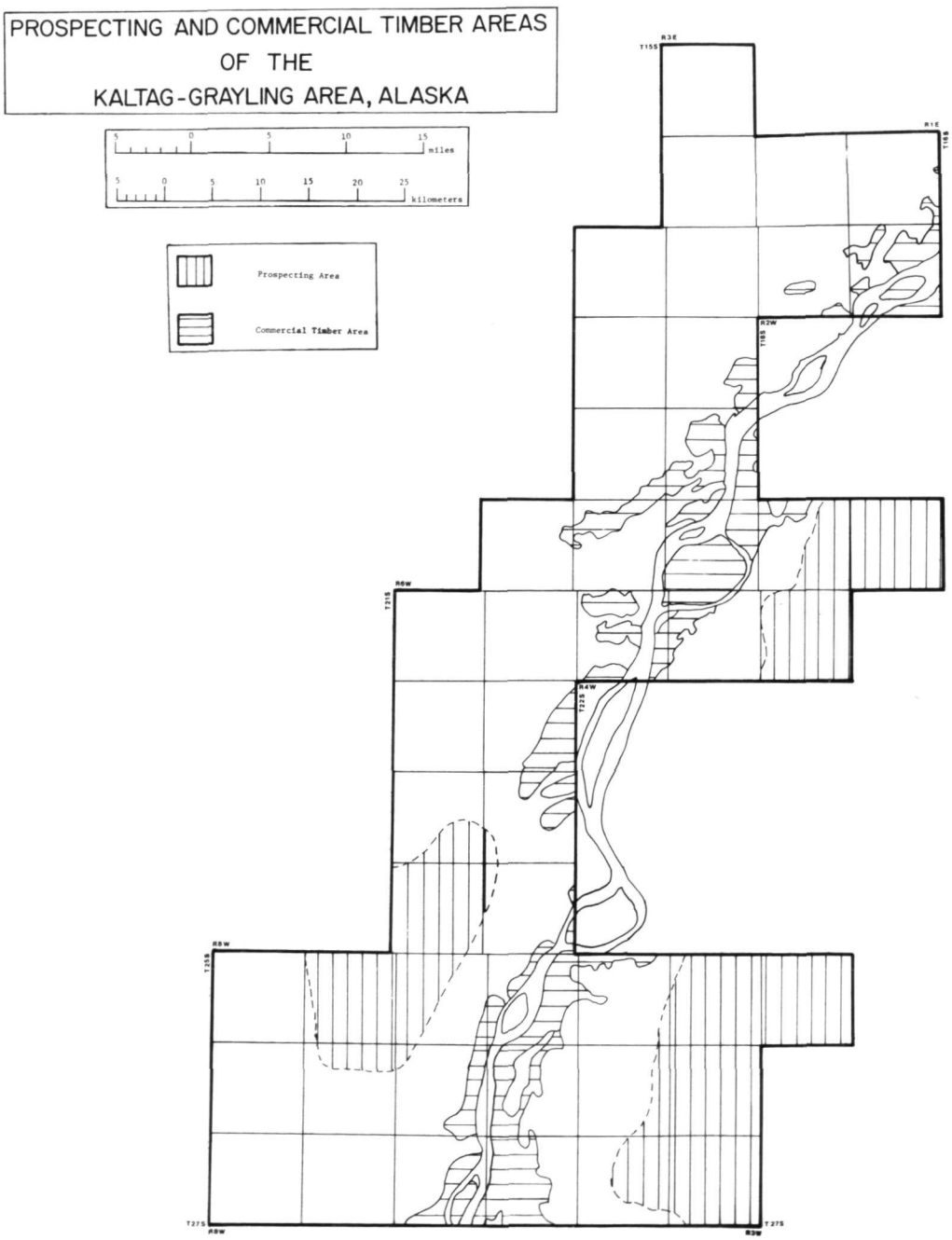


Figure 2. Mineral prospecting areas of the Kaltag withdrawal area. The cross-hatched and vertically stippled regions are the prime regions for exploration.

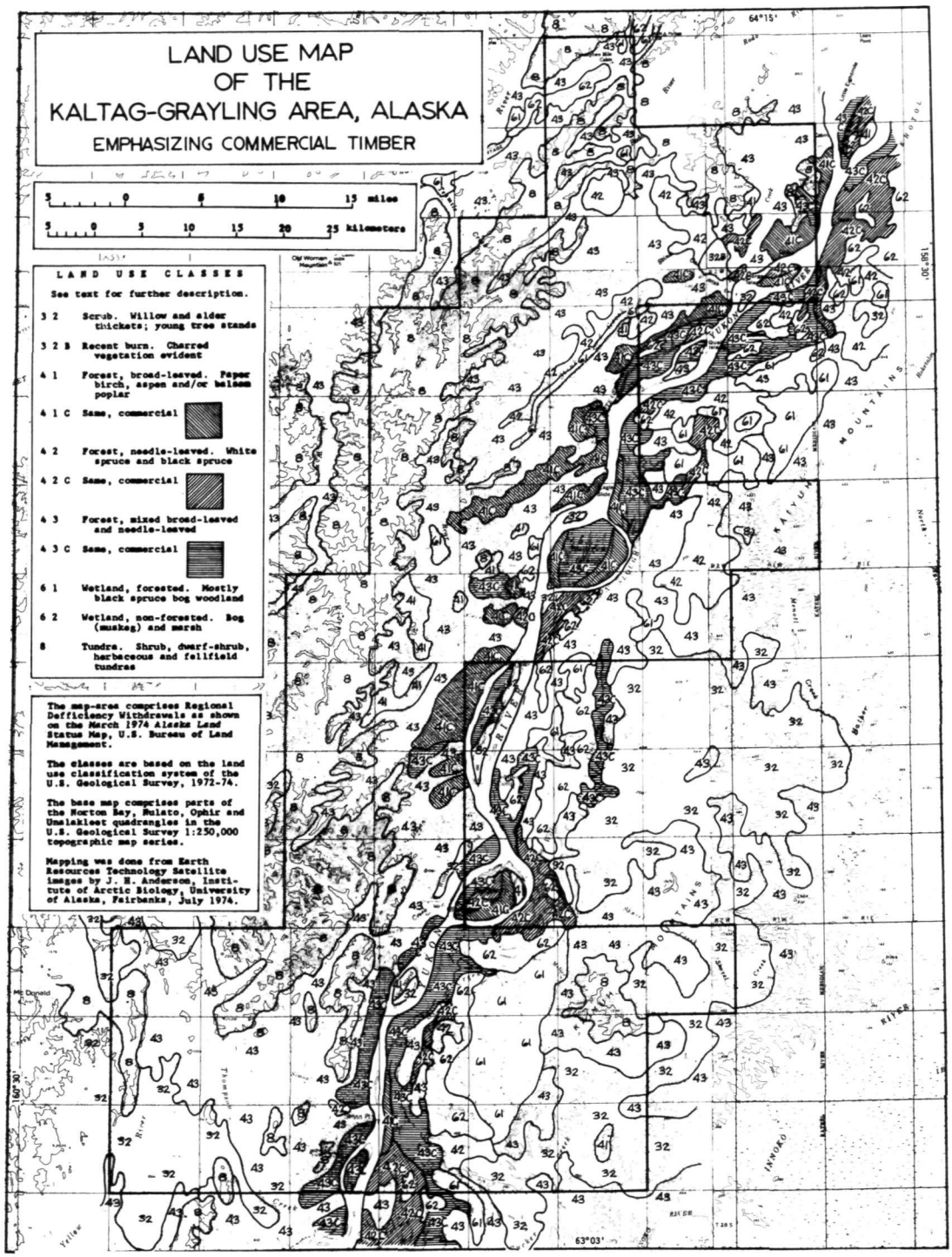


Figure 3. Land-use map delineating 8 major ecological communities. The stippling denotes potentially commercial stands of 3 types of forests.

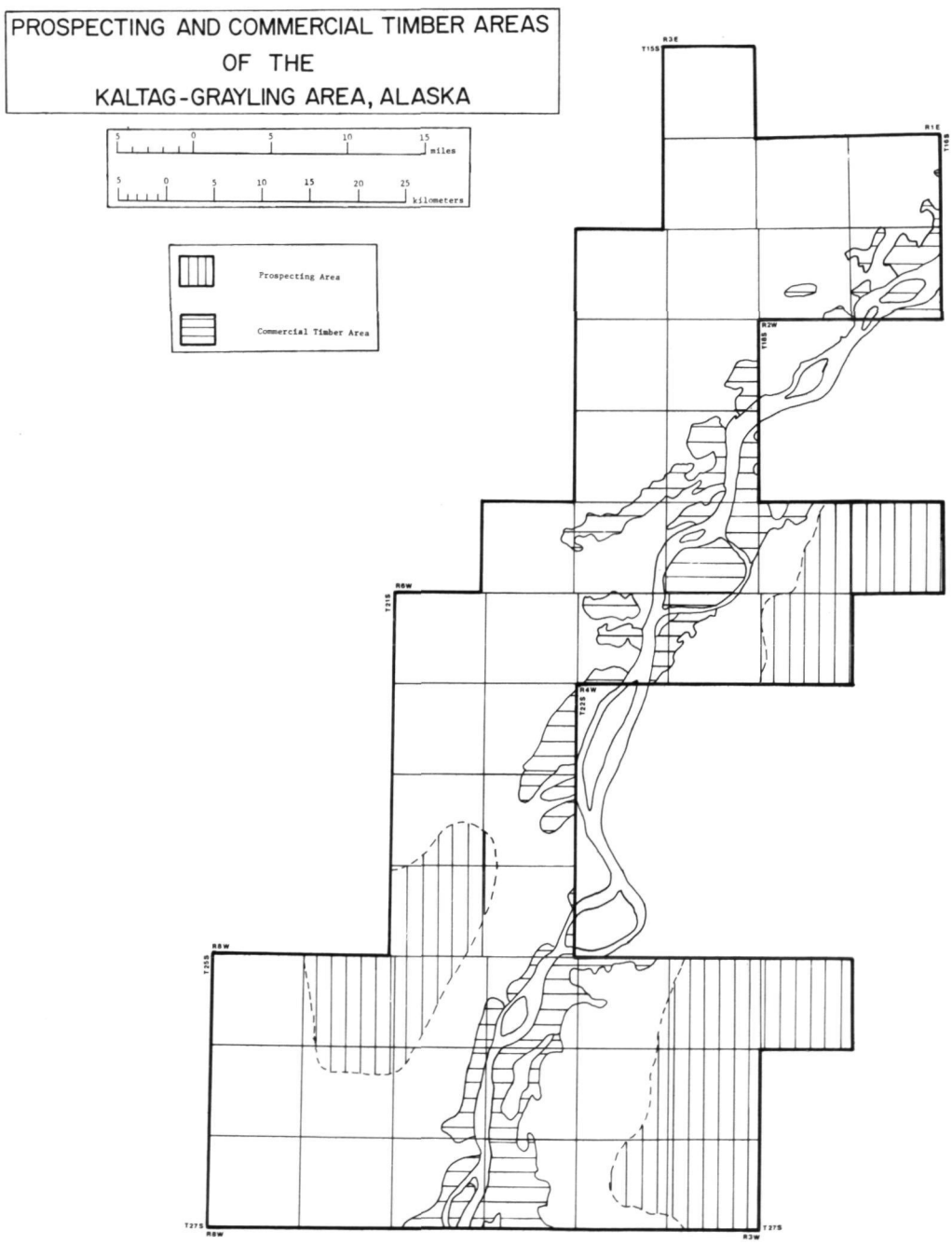


Figure 4. Inventory map for the Kaltag region showing commercial timber and mineral resources.

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THREE EXAMPLES OF APPLIED REMOTE SENSING OF VEGETATION*

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SUMMARY

This paper describes three very different cases in which remote sensing techniques were adapted to assist in the solution of particular problem situations in Texas involving vegetation. In each case, the final sensing technique developed for operational use by the concerned organizations employed photographic sensors which were optimized through studies of the spectral reflectance characteristics of the vegetation species and background conditions unique to the problem being considered. The three examples described are: (1) Assisting Aquatic Plant Monitoring and Control; (2) Improving Vegetation Utilization in Urban Planning; and (3) Enforcing the Quarantine of Diseased Crops.

ASSISTING AQUATIC PLANT MONITORING AND CONTROL

Concept

The infestation and rapid growth of aquatic plants in Texas reservoirs has become a serious state problem.

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These plants have adverse effects on navigation, flood control and drainage, fish and wildlife, recreation, public health, and water quality. The growth and spread of these plants is so dynamic that it has been impossible to monitor and control the infestation by conventional means. The Texas Parks and Wildlife Department, with major funding assistance from the Corps of Engineers, has initiated systematic chemical spray programs costing over $50,000 annually in an effort to eliminate the problem (over $300,000 total expenditure in Texas to date), but the program has been only marginally successful and the aquatic infestation is still spreading each year within affected lakes and into new lakes. It was hypothesized that use of remote sensing techniques could aid in monitoring the species type and growth rate, and in determining more optimum periods and locations for application of chemical sprays.

Procedure

Color and color infrared photography was selected as the basic sensing technique. It was determined that processing control for the films had to be far more stringent than in most work with this approach to assure acquisition of reliable temporal measurements. Repeated flights over an extensive aquatic plant region of Lake Livingston in east



AQUATIC PLANT MONITORING - Lake Livingston, Texas; east end of Jungle area, showing old river channel at right. Area to right of channel is land; area to left is water covered by water hyacinth and duckweed. (Black and white reduction of color infrared transparency).



AQUATIC PLANT MONITORING - Entrance to Beacon Bay Marina. Cloudy patches offshore are areas of hydrilla infestation. (Enlargement of color infrared transparency).

Texas were performed, with supporting ground observations, to develop acceptable flight parameters, exposure settings, film processing procedures, and interpretation guides. Signatures of surface species were shown to provide adequate differentiation, however species such as hydrilla, coontail, and myriphyllum, which have both submersed and emersed states, often require temporal data to insure discrimination when submersed. The procedure established requires careful control of the sensing technique and use of sequential photography throughout the growing season.

Results

The sequential photography showed that there is no single period of youth, maturity, or senescence in the aquatic plants in Texas lakes. Newly emergent areas continually appear, even in mid-to-late season, both on the fringes of mature patches and in completely new areas of the lake. In the case of water hyacinth, new areas of youthful activity reoccur in areas where the mature plants have been sprayed with chemical herbicide. These findings account for the lack of success often experienced with the present herbicide application program.

Sequential imaging showing the effects of herbicide stress indicated repeated patterns of distinct stress

bands, dieback, occasional disappearance of the vegetation mat, reemergence of the youthful plants, and steady and vigorous regrowth in the sprayed areas.

The findings included the following:

- Aquatic plants in Texas lakes are very dynamic systems.
- The seasonal evolution of aquatic plants can be monitored by remote sensing techniques. An estimate of aquatic plant biomass may be feasible.
- The maximum value of the remote sensing approach may be in the accurate monitoring of the effects of chemical herbicide treatments (and probably biological control agents as well) on plant status and regrowth.
- Evidence was found that application of the herbicide 2,4-D in the concentrations presently used may be counterproductive for long-range plant control.
- LANDSAT imagery is useful in monitoring seasonal growth of hyacinth and duckweed in large lakes with known infestations.
- Hydrilla, a particularly noxious aquatic plant species, has been identified on color and color infrared photography and is now known to exist in Lake Livingston.

Payoff

The imagery collected as part of this project has been presented to the Trinity River Authority, Texas Parks Department, Texas Water Quality Board, and EPA. Representatives of these agencies were advised of the documented dynamic proportions of the aquatic plant problem in Texas lakes and of the evidence found that the current control program was inadequate to eliminate the spread of these plants. One of the agencies responsible for the control program in Lake Livingston, the Trinity River Authority (TRA), reevaluated their approach and have adopted a systematic remote sensing survey of the lake for their 1975 season plant control program. The technique developed in this project will be employed during 1975 by Texas A&M University under contract to the Trinity River Authority. These data will also be employed by the Texas Parks and Wildlife Department as part of their chemical spray program. The 1975 work is a pilot project for subsequent application of the approach to other lakes in Texas.

IMPROVING VEGETATION UTILIZATION IN URBAN PLANNING

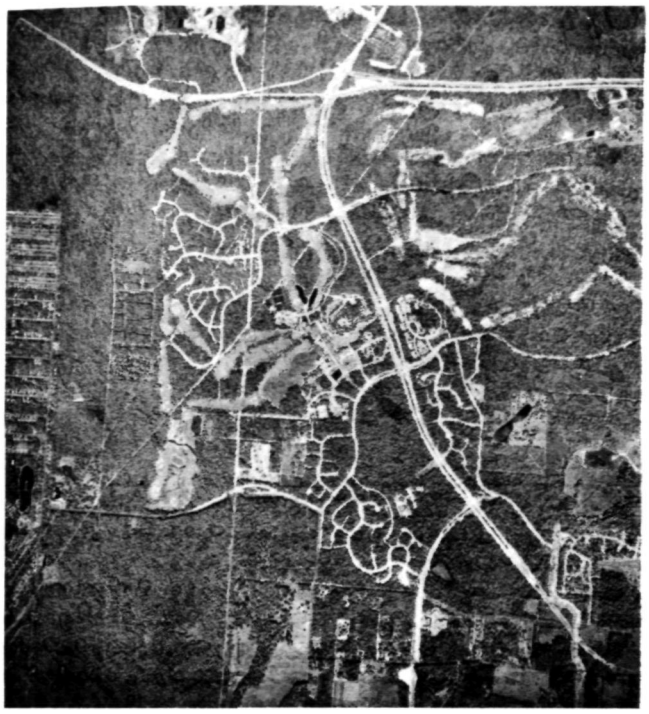
Concept

The Federal Government has authorized the development of certain entirely new planned communities as an experiment

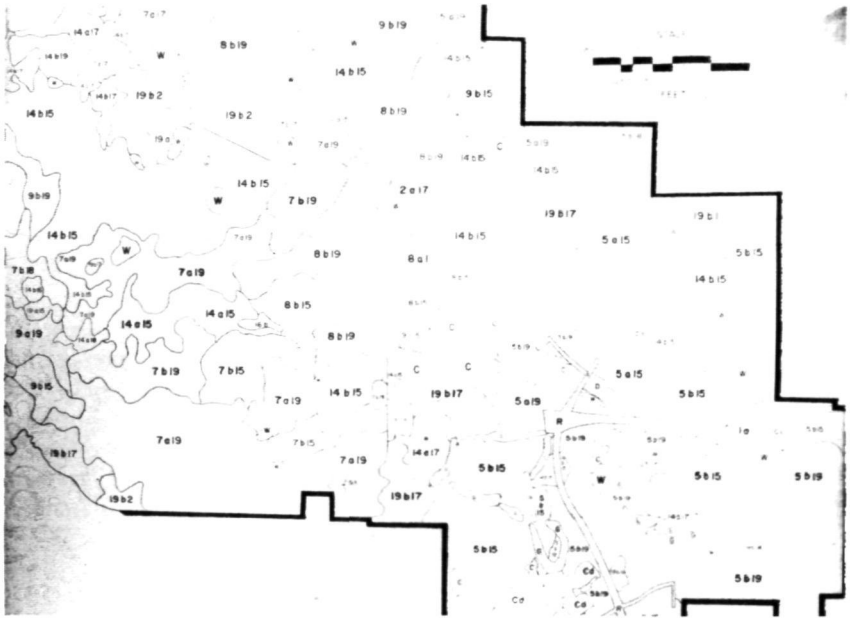
in urban planning with minimum environmental impact. The Woodlands is one of these Title VII communities located 28 miles north of Houston, Texas in Montgomery County. In preparation for this development, Mitchell Associates began compiling extensive background information on the 17,776 acre construction site. This included geologic, topographic, water resources, and soil maps and surveys of wildlife resources. These data were formatted as a series of thematic maps and overlays. An attempt was made to acquire sufficient vegetation information using ground survey techniques in order to supplement these maps. However, it was found that because of the quantity and quality of vegetation information required to support the project planning activities, the ground survey methods were inadequate. It was hypothesized that aerial remote sensing techniques could be used to provide satisfactory vegetation species identification and vegetation distribution maps more rapidly and at less cost than existing methods.

Procedure

The nature of the information required dictated that a ground survey approach must be employed during the initial stages. The objective of the remote sensing procedure developed was to optimize the ground survey and considerably reduce the intensity of the ground sampling.



THE WOODLANDS - Initial development area, showing vegetation types, recreational facilities and cultural features. (Black and white reduction from color infrared transparency).



THE WOODLANDS - Section of vegetation - cultural map made from color infrared photos.

This was accomplished by employing a photo interpretation grid-sampling procedure with color and color infrared photography acquired at a scale of 1:6000. Tests with black and white film and with several grid-sampling methods were conducted prior to developing an acceptably reliable approach.

Results

Color and color infrared photography was used to prepare vegetation maps of critical portions of the Woodlands construction sites. The maps showed location, species, size, and relative health of the vegetation in the area. Ground sampling was substantially reduced, and it was found that an extension of the technique to new areas could be done reliably with virtually no ground verification. A series of vegetation maps were constructed using sequential photography.

The sequential photos proved to be useful in recording construction progress and the impact of construction activities on the vegetation. The definition obtainable from the 1:6000 scale photos allowed examination of individual trees and clumps of underbrush. This gave the developer insight into the undesirable environmental effects of common construction practices. To this end, the developer evolved a system of protective fences and barricades to prevent trees from being barked, shrubs from being overrun, and root systems

from being overcompacted. In certain cases, subcontractors were taken off the project because of damage they had done to the vegetation.

Payoff

The vegetation maps prepared by the Remote Sensing Center were incorporated into the construction planning documents for the Woodlands. These data were used to select the locations of commercial buildings, homes, and roads within the site. The specific benefits obtained as a direct result of the use of these vegetation maps included:

- reduced landscaping costs due to the extensive utilization of the natural vegetation.
- reduced need for artificial drainage systems because of the maintenance of natural ground cover in select areas.
- increased land value and greater profit per acre of development due to limited construction-related environmental degradation.

The remote sensing procedure developed offers the additional advantage that environmental damage due to urbanization can be monitored in a rapid, cost-effective manner. The general methodology developed in this project

has been adopted by the Woodlands developer for his future urban planning activities.

ENFORCING THE QUARANTINE OF DISEASED CROPS

Concept

St. Augustine grass is the primary turf used for lawns and pasture throughout the South. Ninety-six percent of the lawns along the Texas Gulf Coast are St. Augustine. This turf grass was attacked by a strain of Panicum Mosaic Virus, termed St. Augustine Decline (SAD), beginning in the mid-1960's. The damage caused by the virus has been extensive to both homeowners and commercial growers in Texas. Consequently, the Texas Department of Agriculture (TDA) has quarantined all commercial farms pending development of a SAD-resistant grass species. The quarantine has been costly and only partially successful. The TDA spends in excess of $10,000 each year just to survey the diseased crops. The manual survey process requires more than six weeks to complete. An improved survey technique and a more effective quarantine enforcement procedure was needed. It was hypothesized that remote sensing techniques could assist with this state problem.

Procedure

A project was initiated by the Remote Sensing Center in cooperation with the Johnson Space Center to determine a remote sensing technique for the early, reliable detection of SAD virus symptoms. Greenhouse samples, test plots, and commercial fields were measured. Initial results of both spectrophotometer and spectroradiometer readings indicated little spectral signature differences between healthy and diseased grasses in the infrared region and only slight differences in the green region. However, the use of light polarizers showed significant differences in light reflectance in both the red and blue portions of the spectrum.

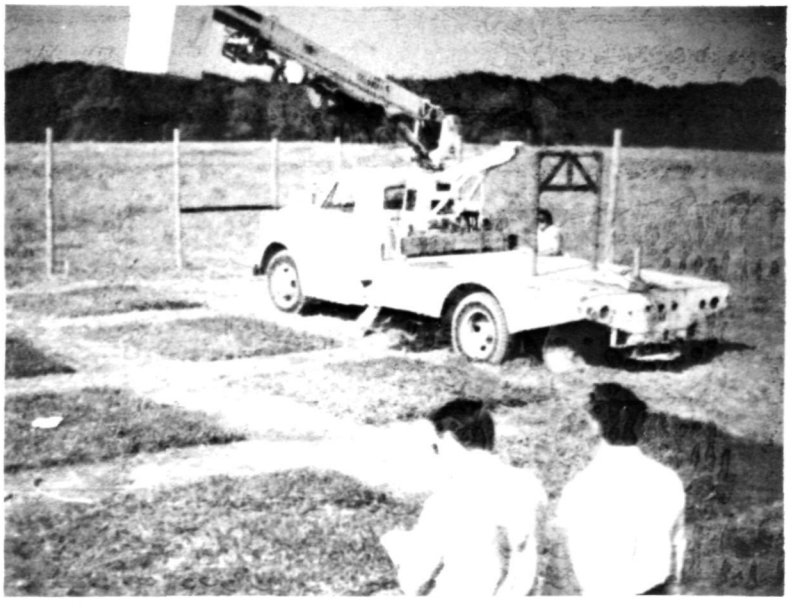
The aerial detection method subsequently developed consisted of four Hasselblad cameras with polarizers using Plus-X film with red, green, and blue filters and black-and-white infrared film with an 89B IR filter.

Results

During the spring of 1974, the Texas Department of Agriculture requested that the Remote Sensing Center fly a SAD detection mission over commercial fields in south Texas. The area included farms that were known to have SAD infested crops. These farmers had been requested by TDA to plow under the diseased areas. However, the farmers had not been responsive



ST. AUGUSTINE DECLINE - Pan American University Campus, lawns infected with St. Augustine Decline. Diseased areas are detectable and intensities differentiable on the original color transparency.



ST. AUGUSTINE DECLINE - NASA truck-mounted spectroradiometer measuring control plantings of SAD-diseased and healthy turf.

to the request and the TDA Quarantine Division was aware of attempts to illegally harvest and ship some of the diseased turf. The farmers were notified by letter from the TDA that their farms would be overflown during March 1974 for the purpose of remote sensing SAD infected areas. On March 4, 1974, just prior to the scheduled flights, a visual inspection of the suspect commercial farms confirmed that all SAD infected grass areas had been voluntarily destroyed by the growers.

Payoff

Whereas the commercial turf grass growers in Texas realized that the existing manual inspection techniques of the TDA were inadequate to enable TDA to properly enforce the state-wide quarantine, the advent of an aerial remote sensing technique convinced the growers that the quarantine could be effectively enforced and, hence, they chose to comply with the TDA regulations.

As a result of this project activity, the Texas Department of Agriculture now has available a reliable, cost-effective remote sensing technique for surveying and enforcing quarantine restrictions on the Texas turf producers.

INTERACTIVE MULTI-SPECTRAL ANALYSIS OF MORE THAN ONE SONRAI VILLAGE IN NIGER, WEST AFRICA L-20

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ABSTRACT

Use of LANDSAT data for identifying and measuring small scale compact human settlements (villages) for demographic and anthropological studies is considerably enhanced with the use of an interactive system. Because village components are not uniformly distributed within any one village, they apparently are multimodal, spectrally. Therefore, the functions of location and enumeration need to be kept separate, at this stage. Measurement of a known village is compared with CCT response.

INTRODUCTION

LANDSAT data, as independent sources of information, are potentially important for analyzing human settlements especially in rural tropical areas where rapid population growth is postulated. The potential of using LANDSAT-1 data in conjunction with other data derived from intensive micro studies has been examined in a number of previous papers (Reining 1973, 1974a, 1974b and 1975a). A primary concern in these papers has been the integration of multiple data sources (orbital imagery, aerial photographs, ground level photographs and anthropological field data) derived from specific, circumscribed test sites. However, extrapolation to the precise context, for which single test sites are examples, has always been a goal. In this paper the results and methodology employed in taking the next step toward this goal are described.

More than one facet of anthropological micro studies can be explored, but elemental first steps are discerning and measuring the small scale, compact human settlements called villages. Not all villages are compact, but approximately half of all village types everywhere, and Sonrai villages in particular, are of this type (Murdock 1957, 1967). Location and extent of villages can be used for demographic enumeration when it can be combined with genealogical censusing. Such censusing can also provide migration rates, as well as fertility and mortality rates and age and sex structure. Censusing and extent of village thus provide an accurate estimate of population density. For villages of a known type and designation, the population density estimate can be used as a "multiplier".

Others are working with LANDSAT for demographic purposes (Ellefsen, Gaydos and Wray 1974, Baldwin 1974, Hsu 1973, Durland 1974, 1975, Lingren 1975, Foresti and de Mendonça 1974) but few are working with tropical rural settlements. We concur with the finding of the Baldwin workshop that field data (ground truth) are relevant if the utility of LANDSAT data for demographic purposes is to be evaluated adequately.

METHODS

In work with LANDSAT data, the unit of measurement equals the unit of observation, or pixel. Therefore, a capability of training on a single pixel is of elemental significance for village identification.

The data sources used in this study are: LANDSAT-1 scene No.1345-09480, 3 July 1973, and No.1272-09433, 21 April 1973, Institute Geographique National 1/50,000 map Gotheye 4c, field data from a Sonrai village, data from a low altitude flight 13 July 1973 over this area, Perille's Analyse de la Situacion Demographique au Niger, 1973, and an interactive multispectral analysis system. Correlation of these data sources makes positive the identification of named Sonrai villages in Landsat CCT data displayed on a color monitor.

Initial work, beyond simple identification, indicates that known Sonrai villages are multimodal in spectral characteristics, suggesting that (1) village components (e.g. houses, compound floors, varying types of roofing, trees, open pathways, tethering places and market places) are not so evenly distributed in every village as to present a uniform, and unimodal, brightness level and (2) until additional work is done the locator function needs to be distinguished from the enumerating or measuring function.

The specific methodology employed follows. As a preliminary to multispectral training and classification with the system, a detailed visual examination of several Sonrai village sites was made. Utilizing the "zoom" magnification Feature of the system, small sections of the image surrounding villages were enlarged and displayed on the color CRT monitor. The LANDSAT-1 CCT digital data stored in the system's refresh memory were used to create the magnified sections, thus maintaining maximum resolution. An 8X magnification was found to be optimum for close examination of the villages.

In the test site area villages range in size from approximately 100 LANDSAT picture elements (pixels) to as few as 3 or 4 pixels. A few single compound settlements were exhibited by only 1 or 2 pixels, while several villages fell in the 20 to 30 pixel size range. For a preliminary study, a small section of the LANDSAT-1 scene was entered into the system at a slightly magnified scale of 2X. At this scale the color monitor image covered 15 x 15 kilometres at approximately 1:50,000. Small areas were then magnified to 8X for selecting training areas. Training on a single pixel appears to be optimal for village components. In operation, a specified training area is delineated on the image under analysis through the use of an adjustable electronic cursor which is both displayed on the monitor and scanned by the hardware for size and position coordinates. The multi-spectral brightness data within the training area are automatically measured, and their limits are used to define a four dimensional parallelepiped in spectral space. Then the entire image is scanned pixel by pixel and compared to the parallelepiped limits. All pixels which lie within the bounds defined by the training data are flagged or alarmed and displayed on the monitor as a color map. This can be done in approximately 5 seconds, and allows iteration. Only places corresponding to identified residential areas (villages) were flagged or alarmed by the initial training data. The residential range is from single pixels to more than one hundred pixels. The single pixels are composed of single quartier, or one compound-cluster villages or settlement areas.

If after a few iterations of the basic training and classification procedure the results are unsatisfactory, other procedures are employed. One of the more valuable complementary procedures is histogram analysis. Each time the system performs a parallelepiped training it calculates and stores complete histogram data for each of the four spectral channels. The operator can call these data to be displayed on the graphics terminal and alter any of the parallelepiped limits as defined on the histograms. Again in real time (1/30 second) he can see the results of any changes he might make, and if necessary, can proceed to other techniques. Of the available options, multiple parallelepiped analysis and cluster analysis were performed. Once the desired classification resluts have been achieved, they are then stored on one of the eight binary channels to form a thematic map which can be displayed on the original image data base.

ANALYSIS

The analysis is based on 8 hours of work with the interactive multi-spectral analysis system.

Extent of Village

A Sonrai village, Koulbagou-Haoussa, was studied in June and July of 1973. A partial reproduction of a 1:50,000 map showing the village appears in Figure 1, a 1972 aerial photograph of the village appears in Figure 2, and a ground photo taken inside the village appears in Figure 3. A black and white photograph of the system monitor, of MSS 6 only, is shown in Figure 4. The response of the village is seen in 6 pixels (8X training window)

also shown in Figure 4. In Figure 5, MSS 7 of the same portion of the scene is shown with some differences among the pixels. The LANDSAT CCT response indicates that the village area is 6 pixels or 27,018 square metres.

Two estimates of the area of the village have been derived from an aerial photograph. A chain used to measure between points readily identifiable in the photograph suggests that the photo is at a scale of 1:6,800. Making that assumption a planimetric measurement of the photo yielded an area estimate of 33,750 square metres while a direct count using a grid provided an estimate of 32,960 square metres. The difficulties inherent in making a simple direct conversion of number of pixels to obtain an area measurement have been examined by Chafaris (1975) among others. It seems quite clear that additional work will need to be done for demographic studies, but Sonrai villages provide a useful range in size, from 1 or 2 to 100 plus pixels and the problem of border pixels under conditions of high contrast should be examined.

Location of Villages

Thirteen out of fourteen named villages occurring on the Gotheye map are flagged following training on one village as may be seen by comparing Figure 2 and Figure 6. All other alarms or flags are smaller (unnamed) settlements corresponding to settlements on the Gotheye sheet, or, in three instances, to likely settlement locations. In short, considerable certainty exists that everything identified is a settlement. However, it is not certain that every settlement is identified -- there may be "underreporting" or response. The classification shown in Figure 6 consists of white spots on a black and white reproduction of a color composite. The horizontal lines are due to data dropouts in MSS 4, which was not used in the classification.

Subsequent Analysis

In general, for subsequent analysis previously derived, spectral signatures or parallelepiped limits can be used by recalling them from storage or re-entering them. Thus, the entire analytical procedure for the new data base does not need to be repeated. But, evaluations can be made as to the accuracy of the new results and additional changes made if needed.

In the two areas studied in this investigation, an attempt was made to transfer the signature. However, it was found that direct transfer was not possible, although the spectral signatures in both cases were similar. This is not unexpected, since the LANDSAT data are from different seasons. In one case, three rather than four channels were used.

A second area, immediately upstream of that shown in the earlier figures, is shown in Figures 7-10. Figure 7 is a background shot of the monitor at a 2X magnification displaying an area approximately 15 km x 15 km. Figure 8 shows an initial classification based on training on the village of Ziguida (see Figure 1). After detailed work with the 2X scene and comparison of the results with maps, a large area was entered into the system at 1X magnification. This scene (Figure 9) covers 30 km x 30 km and contained approximately 190,000 pixels. Three different spectral signatures developed on the 2X test site were applied to the larger area and 561 pixels were identified as being villages. Evaluation of the results is still in progress, although qualitatively they appear to be very good. Figure 10 shows the composite classification of the area. In the area shown in Figure 10, three settlement patterns can be seen: (1) discrete, compact and relatively large villages located on the banks of the Niger River, and on islands in the river; (2) ribbon settlements along minor tributaries; (3) very small, one-compound-cluster village settlements. The last may correspond to rainy season compounds. The greatest source of potential error in demographic enumeration is here, since rainy season compound inhabitants have village houses as well.

Population Growth Rate

The projected population growth rate of 2.83% per year demands a 47% increase in population between 1957, when the IGN aerial coverage was flown, and 1973, when the LANDSAT data used here were acquired. A desirable next step in the investigation is comparison of more recent LANDSAT coverage with the 1973 data for possible or probable (given the projected growth rate) changes in the extent or number of villages.

CONCLUSIONS

1. Small scale human settlements can be identified optically on a color monitor of an interactive multi-spectral analysis system. Such settlements range in size from 1-2 pixels to more than 100 pixels. A significant number show a response to classification procedures.

2. Adequate mapping for the entire area inhabited by Sonrai is not available (Niger, 1972), therefore village location could be estimated by the methodology employed here.

3. Further work with compact villages in the size range of Sonrai villages is thought to be justified to determine the demographic capabilities of this technique.

4. At this stage separation between identification and measurement of villages is an appropriate strategy.

ACKNOWLEDGMENTS

Field data used in this paper were acquired in the course of work conducted under the auspices of contract # AID/CM/afr-C-73-21. LANDSAT CCTS # 1272-09433 and 1345-09480 were made available for this research by Goddard Space Flight Center. Access to the GE Image 100 system was a courtesy of General Electric and Goddard Space Flight Center.

REFERENCES

Baldwin, C. Stephen, 1974, Satellite Data Workshop, May 10, 1974. Paper. The Population Council.

Chafaris, George J., 1975, Area Computation from ERTS data via Image 100. General Electric Paper, 9 January 1975.

Durland, Robert E., 1974, Potential Uses of ERTS Satellite Imagery for Population Studies and Census Activities. Paper presented at the World Population Conference, Bucharest, Rumania.

Durland, Robert E., 1975, Applications of Remote Sensing in Population Estimation in Bolivia and Kenya. Paper presented at the Population Association of America meetings, April 1975.

Ellefsen, Richard, et. al., 1974, Computer Aided Mapping of Land Use Using ERTS Multispectral Scanner Data. Paper presented at First Pan American Congress on Photogrammetry, Photo interpretation, and Geodesy, Mexico City, Mexico, July 1974.

Foresti, E. and De Mendonça, F., 1974, Demographic Inference Using ERTS Images. Seminar on Space Applications of Direct Interest to Developing Countries. COSPAR Brazilian Space Research Institute, Sao Jose dos Campos, p. 239-256.

Hsu, Shin-yi, 1973, Population Estimation from ERTS Imagery: Methodology and Evaluation. Proceedings of the American Society of Photogrammetry. 39:no. 3.

Lindgren, David, 1975, Possible Applications of ERTS Technology for Population Policy Research in the United States, with Special Reference to Metropolitan Planning. Paper Population Association of America Meetings, Seattle, April 1975.

Murdock, George P., 1957, World Ethnographic Sample. American Anthropologist 59:664-687.

Murdock, George P., 1967, Ethnographic Atlas: A Summary. Ethnology 6:no 2. April.

Niger Publication Carte Au 1:50,000, Situation au 31 Decembre 1972.

Reining, Priscilla, 1973, Utilization of ERTS-1 Imagery in Cultivation and Settlement Site Identification and Carrying Capacity Estimates in Upper Volta and Niger. National Technical Information Service, Springfield, Virginia E 74 10813.

Reining, Priscilla, 1974a, Human Settlement Patterns in Relation to Resources of Less Developed Countries. Proceedings of Seminar on Space Applications of Direct Interest to Developing Countries. COSPAR: Brazilian Space Research Institute, Sao Jose dos Campos.

Reining, Priscilla, 1974b, Earth Resources Technology Satellite 1 Data and Anthropology. Paper presented at the American Anthropological Association Meetings, Mexico City, Mexico, D.F. November 1974.

Reining, Priscilla, 1975a, The Demographic Potential of ERTS-1 Data. Paper presented at the American Association for the Advancement of Science meetings, New York City, January 1975.

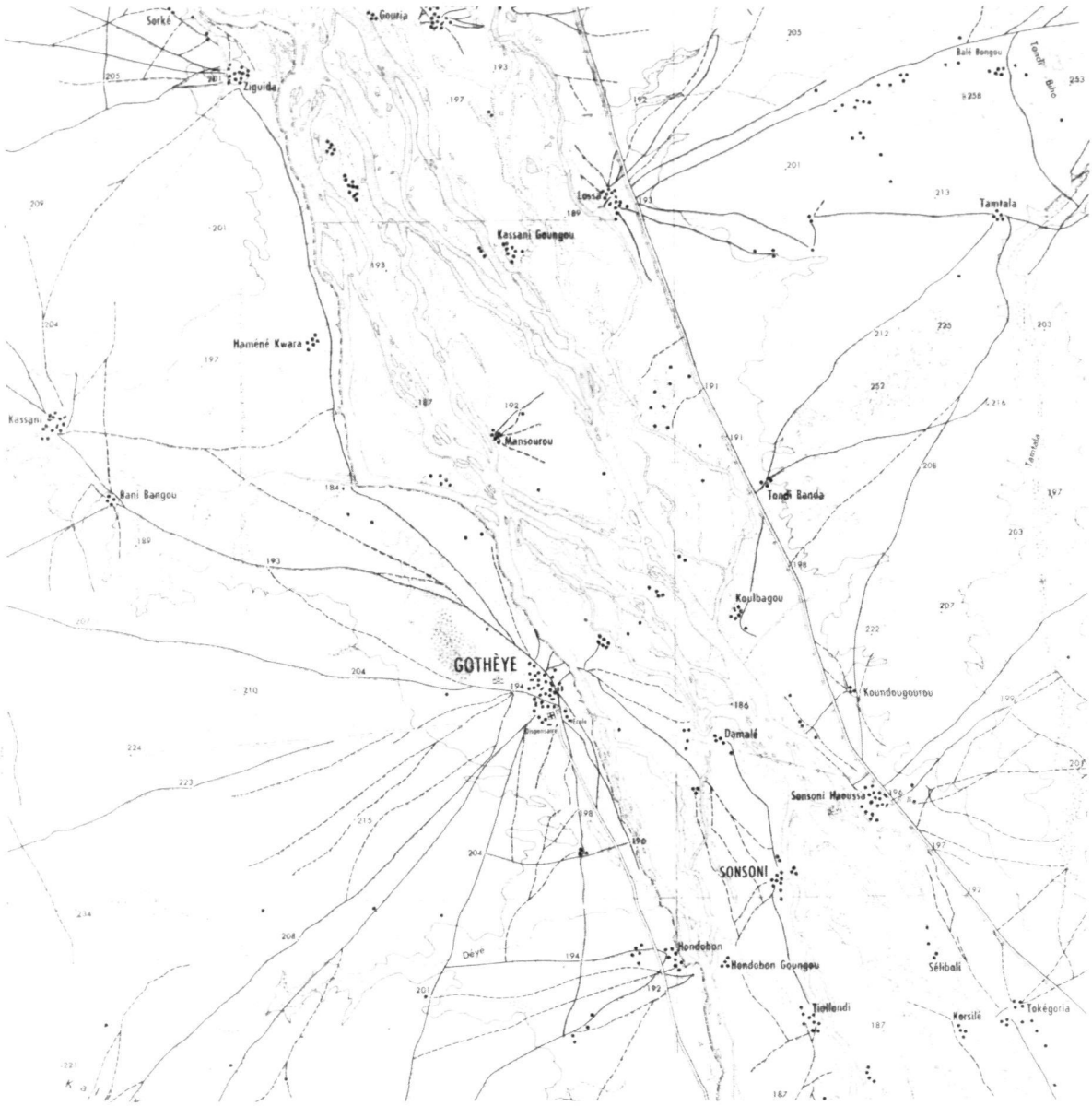


Figure 1. Portion of a 1:50,000 scale topographic map along the Niger River near the villages of Koulbagou-Haoussa and Ziguida. Map reduced to approximately 1:28,000.

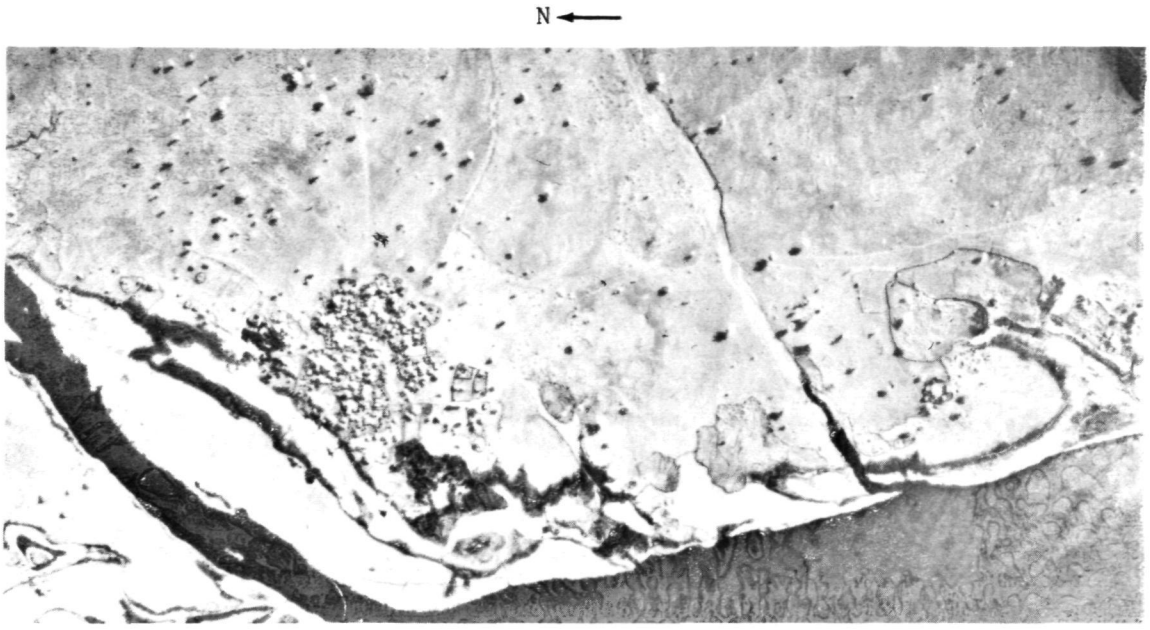


Figure 2. Aerial photograph showing the village of Koulbagou-Haoussa. Photo covers 750 by 1750 meters (scale = 1:10,000).



Figure 3. Ground photograph of the village of Koulbagou-Haoussa.

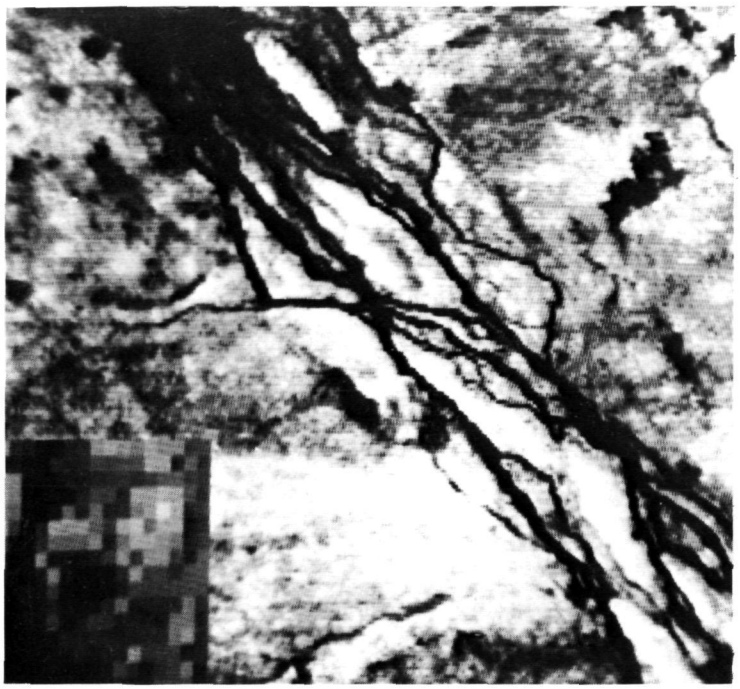


Figure 4. Television monitor display of a 15 x 15 km portion of MSS band 6 ID No. 1272-09433. 8X "window" (lower left) is centered on the village of Koulbagou-Haoussa.



Figure 5. Television monitor display of MSS band 7 for the same scene shown in Figure 4.



Figure 6. Classification results (white) superimposed on black and white rendition of color composite television display for same scene shown in Figure 4.

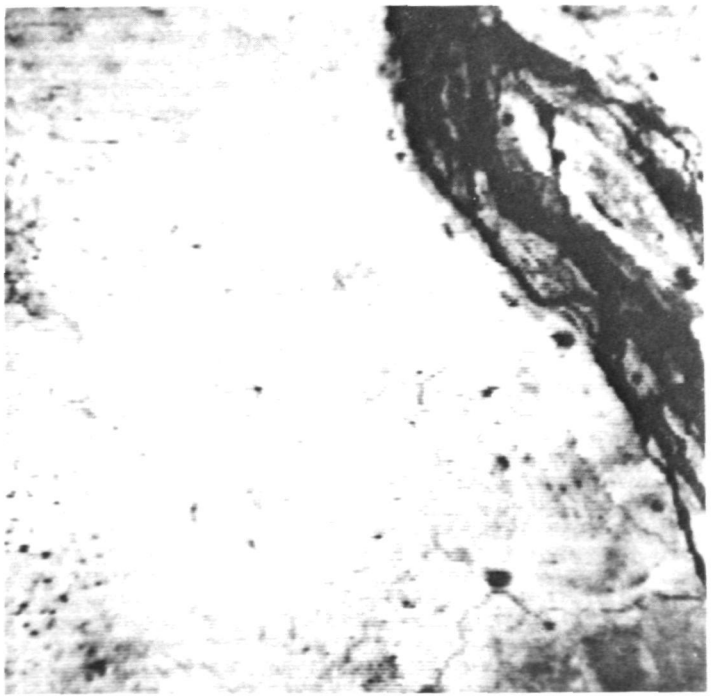


Figure 7. Black and white rendition of color television display for a 15 x 15 km area surrounding Ziguida (Scene ID No. 1345-09480).



Figure 8. Results of classification (white) for scene shown in Figure 7. Training area (Ziguida) is shown in the 8X window (center left).

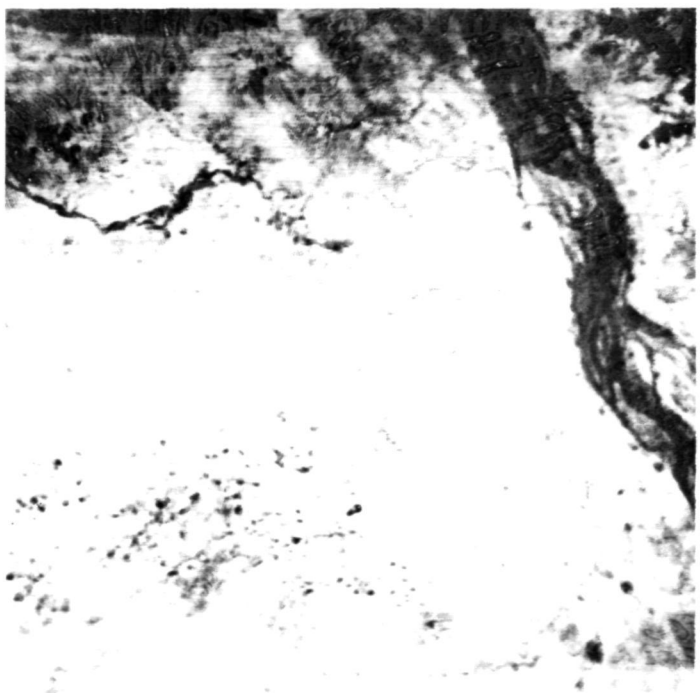


Figure 9. Black and white rendition of a color monitor display of a 30 x 30 km portion of scene ID No. 1345-09489 along the Niger River, near the village of Ziguida.

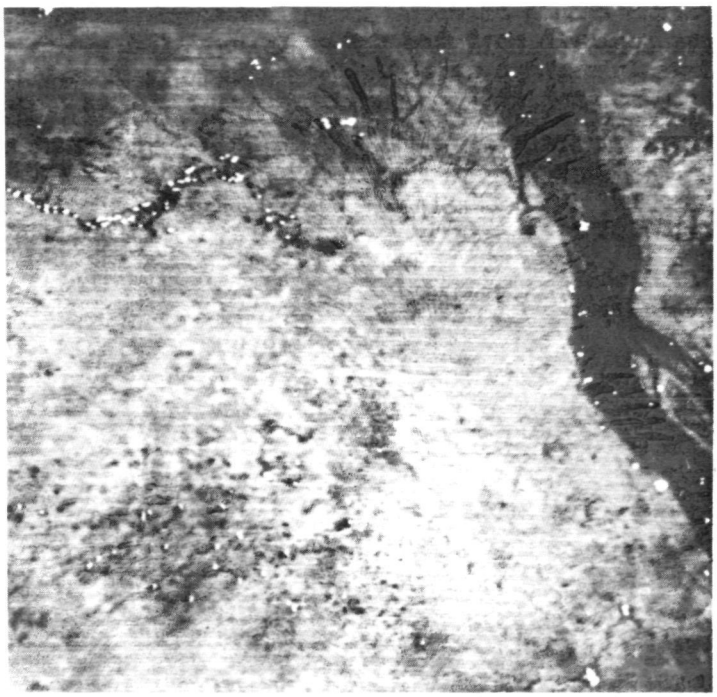


Figure 10. Classification results (white) for scene shown in Figure 9. These results are for the same spectral signature (from training on Ziguida) as in Figure 8.

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PRESENT AND POTENTIAL LAND USE MAPPING IN MEXICO

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ABSTRACT

The Mexican Water Plan (MWP) conducted studies of present and potential land use in Mexico using LANDSAT-1 satellite imagery. Funds were provided by the Mexican government and by the United Nations. The World Bank was the executing agency for UNDP fund and assisted also in selecting and hiring foreign personnel.

Present land use studies were carried out all over the country (197 million hectares); nine soil uses were mapped according to the first classification level recommended by the U. S. Geological Survey. Also 6.3 million hectares of land with advanced erosion were detected. Work was executed at a rate of 8 million hectares per month; reliability was 90% and the cost of only 0.1 cents/hectare.

The potential land use study was performed in 45 million hectares at a rate of 4 million hectares per month and at a cost of 0.33 cents/hectare. Soil units according to FAO classification were delineated scale 1:1 million; interpretative maps were also prepared dealing with potential agricultural productivity carrying capacity for cattle, water, erosion risk, and slope ranges.

INTRODUCTION

By the end of 1972, the Mexican Water Plan (MWP) started working with its main objective of developing systematic water resources planning procedures for the country. The Mexican Government made an agreement with the United Nations Development Program in order to make use of foreign expertise when needed. At the same time, it made a commitment of sharing the MWP's experiences with other countries. One fourth of the 4 million dollar project was provided by the UN, and the rest by the Mexican Government. The World Bank was the executing agency for the UNDP funds, providing assistance in selecting and hiring foreign experts.

In Mexico, agriculture is by far the largest water consuming activity. Water resources planning is thus carried out within a physical framework, where the two most important resources are water and soil. This physical framework strongly interacts with a comprehensive socio-economic framework in the planning process.

METHODS

Figure 1 shows the Mexican soil studies stages using LANDSAT Satellite imagery. The MWP defined a work program for a 33 month period project, which included soil inventories as one of the main inputs. Water requirements for irrigated agriculture accounts for more than 95% of the country's total water consumption. Therefore, soil inventories are as import as water inventories for successful water resources planning.

Only the FAO soils map was available for the whole country, as well as many local soil studies covering small areas, when the MWP project was started. Very good present and potential 1:50,000 scale land use maps are being developed in Mexico by CETENAL (Comisión de Estudios del Territorio Nacional). Unfortunately, the FAO soils map is too general, and not suitable for water resources planning. On the other hand, CETENAL maps are excellent but cover less than a third of the country at present time.

The MWP staff defined the objectives for the present and potential land studies and sketched preliminary procedures. Afterwards, two seminars were conducted in Mexico City in order to define the final procedures to study present and potential land use using LANDSAT-1 imagery.[1/] A well experienced U.S. Soil Conservation Service scientist and two leading U.S. experts in LANDSAT imagery were selected to participate in the seminars.

The whole country was surveyed with present land use studies and maps scale 1:1 million were prepared, while only 45 million Ha were covered with potential land use studies. The areas to study potential use were selected from regions with less than 10% slope where water is still available for agriculture development.

A short training course on image interpretation for present land use purposes was then given by one of the remote sensing experts, and a Mexican consulting firm conducted the study. In a two-year period the whole country was mapped at a 1:1,000,000 scale with a cost of 200 thousand U. S. dollars, i.e. 0.1 cents/hectare. The areas where potential land use studies would later be carried on were given first priority.

The potential land use study was started 6 months later since present land use information was needed as an input. The other LANDSAT expert and the soil scientist led two pilot studies while adjusting the proposed methodology, along with experienced soil scientist of another Mexican consulting firm. They made six one-week trips to Mexico during the following year to carry on the study. With each trip, they functioned more as a review team, while the leadership and responsibility of the study was turned over to the Mexican soil scientists. More than a fifth of the country was studied in a year with a cost of roughly 150 thousand dollars; i.e. 0.33 cents/hectare. Also 1:1,000,000 maps were finally produced.

The results of both present and potential land use studies have improved the Mexican soil resources inventories as a by-product of the water resources planning itself. The integration of results contributed significantly to improve the regional water resources planning process.

A summary of results of both studies, as well as their integration is presented. Finally, to accomplish the commitment with the United Nations, an outline of a step-by-step handbook to make land use studies using LANDSAT imagery, presently under preparation, is submitted for discussion. Suggestions from the Symposium will help MWP in making a useful contribution to the field of remote sensing technology.

1/ Garduño, H., García Lagos, R., García Simo, F. y Pérez Gavilán, D., UTILIZACION DE LAS IMAGENES DEL SATELITE ERTS-1 EN LA PLANEACION DE LOS RECURSOS HIDRAULICOS, Primer Congreso Panamericano y Tercero Nacional de Fotogrametría, Fotointerpretación y Geodesia, México, 1974.

PRESENT LAND USE STUDY

The objectives of this study were:

1) To survey present land use in the whole country. Special emphasis was placed on irrigated agricultural land and on rainfed areas.

2) To provide basic information to determine potential land use and to compare later the results of present and potential land use studies.

False infrared color transparencies using channels 4, 5, and 7 from LANDSAT were used. The U.S. Geological Survey First Classification level recommendations[1/] were followed with slight modifications to interpret the 200 images that cover the country. Since agricultural land was the main interest of study, images taken during the dry and rainy seasons were used. This made it possible to discriminate irrigated from rainfed agriculture.

The project included intensive low altitude flights and ground-truth trips, as well as comparison with detailed 1:50,000 CETENAL maps. Table I shows the reliability for each present land use mapped.

In southeastern tropical Mexico Skylab IR color photographs were used where cloud-free LANDSAT images were not available. Since only visual interpretations techniques were used, those areas densely covered by vegetation were especially difficult to interpret. Future efforts will also utilize methods which take advantage of spectral computer-aided scanning.

TABLE I. RELIABILITY OF THE PRESENT LAND USE STUDY RESULTS

Land Use	Code	Minimum mapping Unit	More common mixed interpretations	Reliability %
Irrigated cropland	(1)	50 Ha	(2) and (3)	95
Flat rainfed cropland	(2)	100 Ha	(1) and (3)	90
Steep rainfed cropland	(3)	150 Ha	(1) and (2)	85
Range and grassland	(4)	250 Ha	(3) and (7)	85
Woodland (conifer and hardwood)	(5)	250 Ha	(6) and (7)	90
Tropical forestland	(6)	250 Ha	(5) and (7)	85
Shrub/Scrubland	(7)	250 Ha	(5) and (6)	85
Barren land	(8)	300 Ha	(4)	85
Wetland	(9)	200 Ha	(1)	95
Water bodies	(a)	50 Ha		98
Urban areas	(u)	100 Ha		95
Erosion	(e)	300 Ha		85
Average				90

Note 1. The two uses more intensively field checked were irrigated and rainfed land.

Note 2. Water bodies and urban areas were easily identified.

1/ U.S. Geological Survey, A LAND CLASSIFICATION SYSTEM FOR USE WITH REMOTE-SENSOR DATA, Geological Survey Circular 671, Washington, D. C. 1973.

Results

The final results are now being printed in 17 land-use 1:1,000,000 charts (Fig. 2). Each map includes a detailed description for each use, which takes into account regional differences found within the country. A grid formed by squares of one half degree latitude and one half degree longitude was superimposed onto the maps and supporting area statistics were calculated for each land use type on the basis of state, MWP regions and individual charts. The hectares covered by each used with advanced erosion was also computed. Fig. 2-A shows a generalization of results for the whole country.

Comparison with censal figures is usually meaningless due to differences in land use definitions; however, it is interesting to point out that while censal data indicated that an area of 30.0 million Ha is completely eroded, the present land use study detected only 6.3 million Ha of land with advanced erosion.

Duration, Manpower, and Cost

Figure 3 shows the schedule of activities for the present land use study. Once the procedure was defined and the interpreters trained a set of straight forward steps were followed for each one of the 17 land use charts. However, a major change was made in the original methodology, when ground truth proved to need a far greater effort than was at first anticipated.

Table II shows the manpower used in the study and Table III shows an estimate of costs for the whole study which covered 197 million hectares. The reported total cost of U.S. $200,000.00 doesn't cover air checking nor foreign personnel expenses.

TABLE II. MANPOWER REQUIRED FOR PRESENT LAND USE STUDY

Mexican personnel	Man months
Project manager	26
MWP project coordinator	3
Image interpreters	112
Chartographic support assistants	29
Assistants land use area estimation	90
Draftsmen	64
	329
Foreign personnel	
Remote sensing expert	1

TABLE III. COST OF PRESENT LAND USE STUDY

Image and photographic material	8%
Image interpretation	35%
Chartographic support	7%
Ground truth	15%
Land use area estimation	22%
Drawing and reports	13%
	100%

POTENTIAL LAND USE STUDY

Description

The objective of the study was to assess, at an identification and not a project level, areas with high, medium or low agriculture and pasture productivity and water erosion risk.

Since the project also aimed at the development of methodology to be used, two pilot studies covering 6 million Ha were first carried out in a semi-arid and in a humid tropical area. The area covered was of a reasonable size and the ecological conditions different enough as to assure that the methodology could be successfully applied in any other region of the country.

Interpretation of infrared false color and channel 5 images was made using transparencies and prints, both at 1:1,000,000 and 1,500,000 scales, although final results were produced at 1:1,000,000 scale. Overlays with general delineations of present land use maps, geology, rainfall, FAO soil units and infrastructure were used to help image interpretation. Also more reconnaissance flights and ground truth trips with more intensive sampling were required than by the present land use study.

The soil units classification was taken from the 1:2,000,000 scale FAO map, but a far more detailed soil units map was produced after interpreting the images with the aid of the overlays mentioned above as well as the air and ground truth. The potential land use classification mas made according tho Handbook 210 of the U.S.Soil Conservation Service.[1/]

Finally, interpretative maps were produced for agriculture and pasture use, slope classification, and water erosion risk. A reliability of 80% to 90% was determined by comparing results of the study with available more detailed results of conventional soil surveys.

Results

Figure 4 shows the soil unit delineations obtained following the FAO soil classification system. Image interpretation was determinant in defining more precisely the soil unit boundaries and produced more details than the original FAO map showed.

Potential land use maps were prepared based on the properties of the FAO soil units, yield and production statistics, results from agriculture and livestock experimental stations, field observations, and personal experience of the soil scientists that carried out the study. Estimates of yields were made for the most important crops as well as evaluations of carrying capacity under grass for cattle feeding in each soil unit. Figure 5 shows the general results for agriculture productivity.

Only 17 million Ha were found to have high and moderate agricultural potential productivity. This figure seems low, taking into account that the study was carried out in selected areas according to slope. However, large areas in the south east were classified under present conditions as of low productivity due to seasonal flooding. It is believed that with adequate flood protection and drainage measures, they could easily be considered as areas of high productivity since the soils are deep, flat, and fertile.

The potential range and grass productivity was determined only in 29.7 million Ha since estimates of carrying capacity per hectare were not available in the north western and central regions of the country. Figure 6 shows the general results. A large proportion of the area

1/ Klingebiel, A.A., and Montgomery, P.H. LAND CAPABILITY CLASSIFICATION. Agriculture Handbook No. 210, Soil Conservation Service, U.S. Department of Agriculture, 1973.

was found to have from medium to high productivity (23 million Ha). Most of the land is located in the Gulf coastal plains and on the south eastern regions where most of the country's present livestock production is concentrated.

Finally, Figure 7 shows areas with different degree of water erosion risk. Even though the studied areas lie mostly on flat lands, 69% of the 45 million Ha shows medium to high water erosion risk. This fact points out the need for sound soil conservation programs and policies.

Duration, Manpower, and Cost

Figure 8 shows a schedule of activities for the potential land use study. A line-production procedure was not feasible and separate package studies were carried out in each selected area. The reason for this is that integration of image interpretation, basic data, field notes and personal experience should be borne to a great extent in the mind of the soil scientist in order to finish up a specific area. Hence, one area had to be finished by each team before starting studies on the next one. Two teams were responsible for the whole project.

Table IV shows the manpower used in the study and Table V shows an estimate of costs for the whole study which covered 45 million hectares. The reported total cost of U.S. $150,000.00 doesn't cover air checking nor foreign personnel expenses.

TABLE IV. MANPOWER REQUIRED FOR THE POTENTIAL LAND USE STUDY

Mexican personnel	Man months
2 Team leaders	22
2 Soil scientists	22
2 Image interpreters	22
2 Draftsmen	20
MWP	2
	88
Foreign personnel	
Soil scientist	2
Remote sensing expert	2
	4

TABLE V. COST OF POTENTIAL LAND USE STUDY

Overlay material and image prints	2%
Office work: preliminary delineation, source material analysis and final integration to obtain soil unit maps and interpretative maps	56%
Field reconnaissance trips	26%
Drawing and reports	16%
	100%

THE ROLE OF LAND USE STUDIES IN WATER RESOURCES PLANNING

The comparison of potential and present land use maps shows that 82% of total land now being farmed and rated as high agricultural productivity is being used at present time with irrigatted and rainfed flat land agriculture. However, there are 535 thousand Ha of low productivity areas presently being irrigated and 3.6 million Ha with rainfed agriculture of the same productivity class. On the other hand, 3.9 million Ha with high potential agricultural productivity remain unfarmed.

It is also important to point out that 41% of 16.6 million Ha presently being used within the area studied, are in high danger of being eroded. Most of these areas have rainfed agriculture, since most irrigated land lies in areas with low risk of erosion. This was expected, as well as the fact that 15.6 million Ha with medium to high risk of water erosion are not being farmed.

There are large areas in the Gulf coastal plains with low potential agricultural productivity and medium to high risk of water erosion. These areas should be mainly devoted to pasture land, taking care not to over-graze them.

Detailed studies using these results are presently carried on at MWP in order to define future regional water resources development related to agriculture, livestock, and soil conservation.

OUTLINE OF A STEP-BY-STEP SOILS HANDBOOK USING LANDSAT SATELLITE IMAGERY

The MWP soils group is preparing a handbook covering the points outlined below.

Comments and suggestions from the Symposium participants are welcome. It is important to point out that for the sake of clarity it is intended that each step will be illustrated in detail with figures and in a general way, the results for the whole country will also be discussed.

1. Introduction

2. Present land use

   Objectives
   Classification criteria
   Satellite image selection
   Air reconnaissance and ground truth trip
   Interpretation adjustments
   Land use area estimation
   Reliability criteria
   Cost estimates
   Report writing and graphical presentation

3. Potential land use

   Objectives
   Work teams
   Image transparencies and prints
   Basic source overlays
   Classification criteria for soil units and for land capability
   Preliminary soil units delineation in the office

Air reconnaissance and ground truth trips
Adjustments, final delineations, and interpretative maps
Reliability criteria
Cost estimates
Report writing and graphical presentation

4. Examples of interpretative maps worked out

5. Integration of present and potential land use studies

CONCLUSIONS

The use of LANDSAT imagery has made it possible to make land use inventory maps scale 1:1,000,000 in Mexico with an extremely low cost in a two-year period. The Agriculture Ministry is already carrying out a new inventory scale 1:500,000.

The objectives of the present land use study were met, with an overall reliability of 90%. However, only a small fraction of the information contained in the images was used.

The next steps in using LANDSAT in Mexico will include study of dynamic changes in land use, computer aided spectral scanning, more detailed studies of areas of interest at wider scales (1:250,000), etc.

The potential land use maps were developed faster and at a lower cost than would have been possible using any of the conventional methods. A reliability of 90% was also accomplished in these studies.

The integration of both present and potential land use maps is extremely useful in providing orientations for regional development of water resources in agricultural countries with sparse water supplies; it also helps to set forth policies about land redistribution according to capability and water erosion risks.

ACKNOWLEDGEMENTS

Messrs. Gerardo Cruickshank, Undersecretary of Planning at the Water Resources Ministry and Fernando González Villarreal, General Coordinator of the Mexican Water Plan supported and oriented the land use studies.

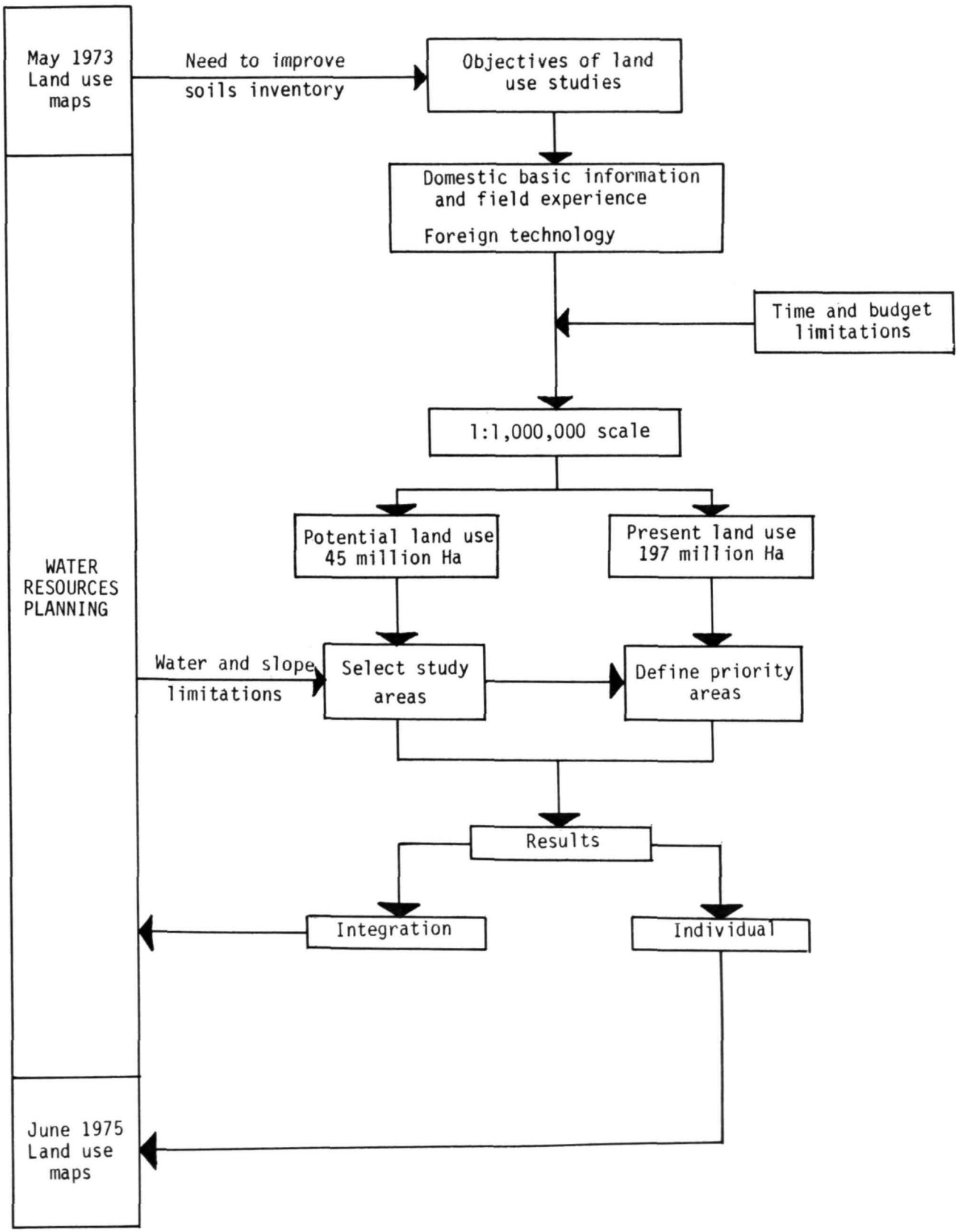
Dr. Donald Lauer in charge of training programs at the EROS Data Center of the U.S. Geological Survey, helped in defining the present land use study methodology, trained the image interpreters and recently made an appraisal of the final results.

Dr. Albert Klingebiel, one of the more experienced U.S. soil conservation scientists, recently retired from the Soil Conservation Service and Dr. Victor Myers, Director of the Remote Sensing Institute at the University of South Dakota, helped in defining the potential land use study methodology and trained Mexican soil scientists on the field. They were also responsible for assistance during the air and field reconnaissance and the reviewing of manuscripts.

Roberto Vital from MWP was in charge of preparing source material, map generalizations and integration of present and potential land use.

The EROS Data Center provided excellent service in processing and sending the images that were required for the study.

Figure 1. Stages of Mexican soil studies as an input to water resources planning



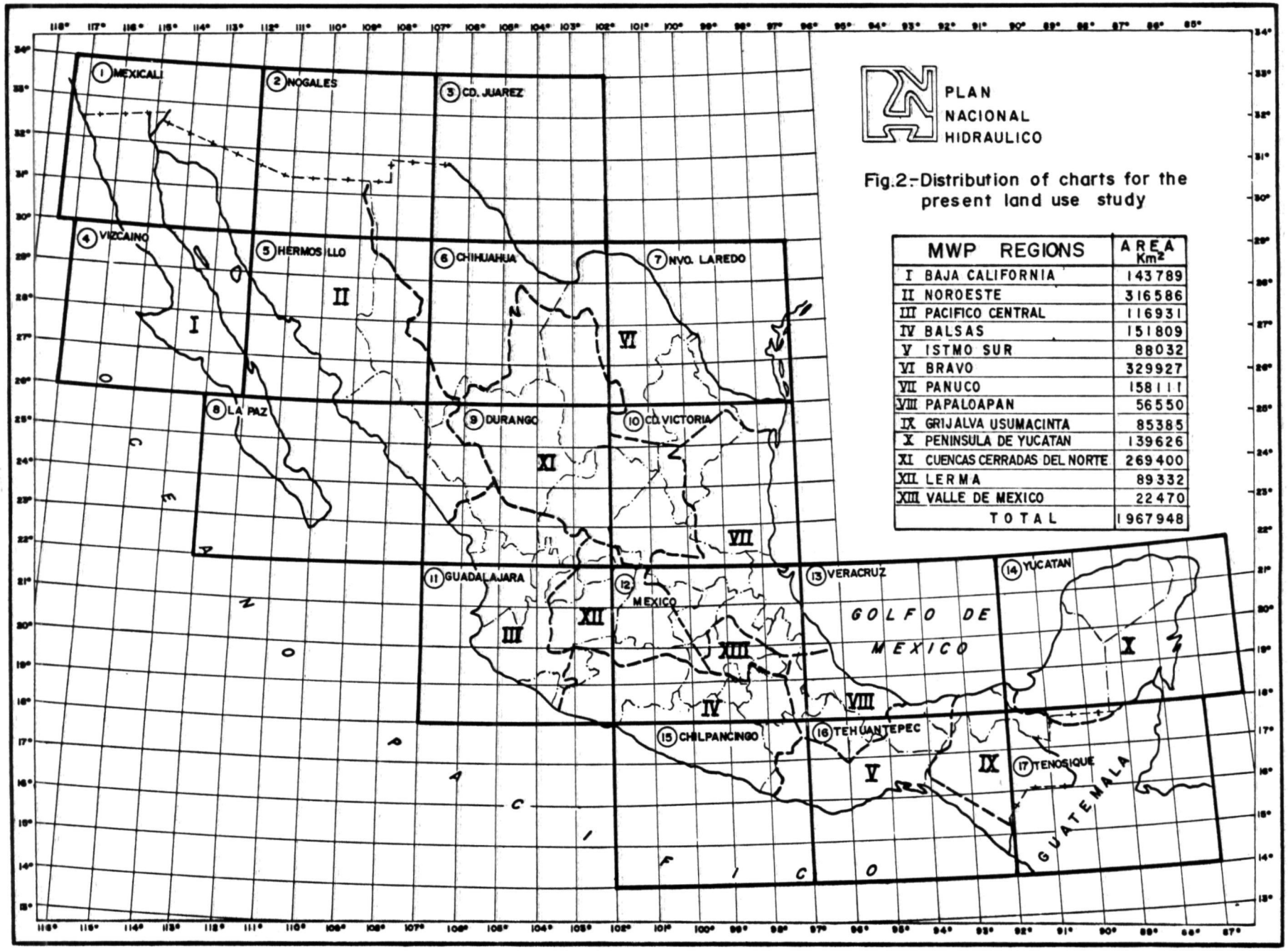
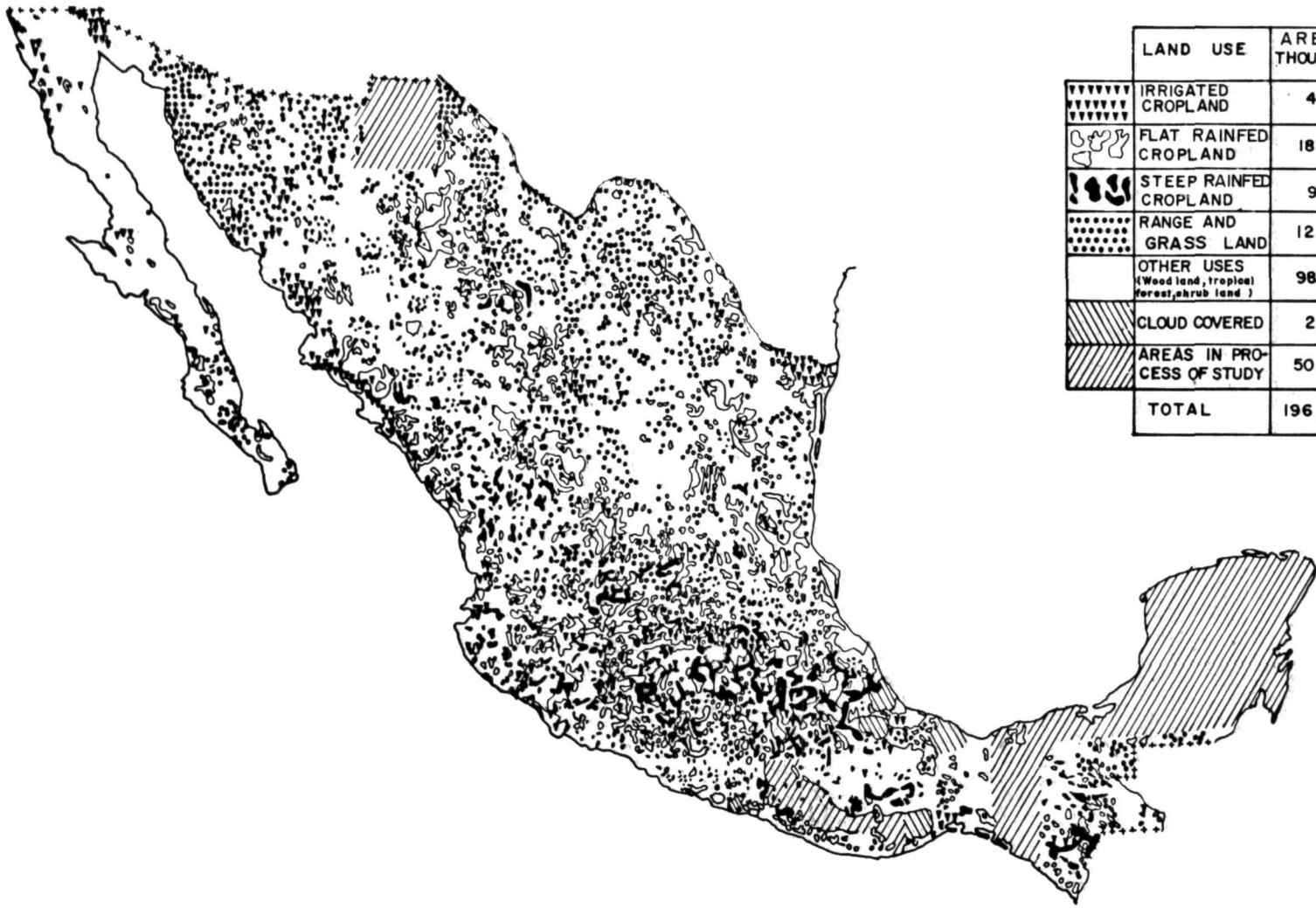


Fig.2:-Distribution of charts for the present land use study

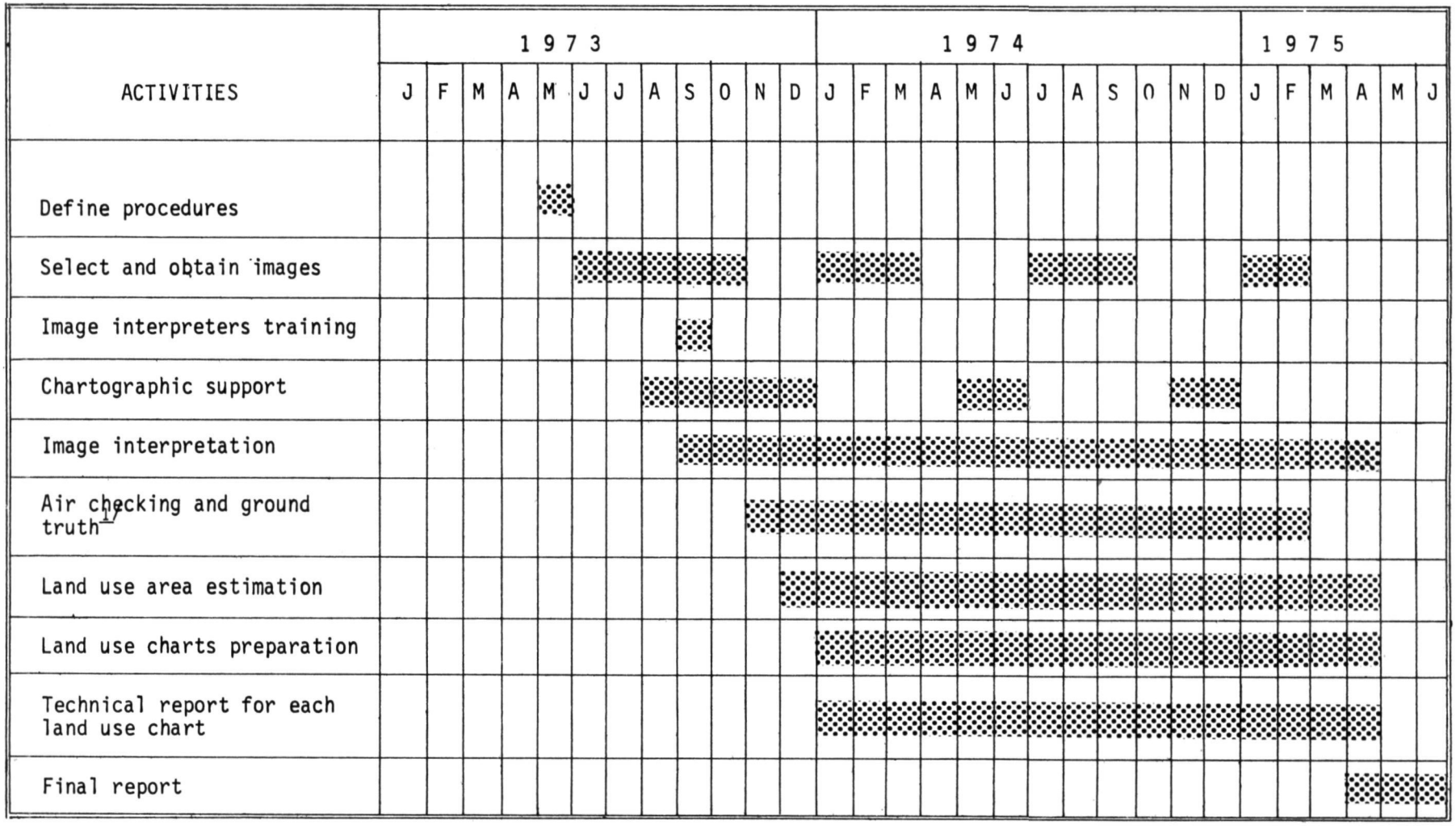
MWP REGIONS	AREA Km²
I BAJA CALIFORNIA	143789
II NOROESTE	316586
III PACIFICO CENTRAL	116931
IV BALSAS	151809
V ISTMO SUR	88032
VI BRAVO	329927
VII PANUCO	158111
VIII PAPALOAPAN	56550
IX GRIJALVA USUMACINTA	85385
X PENINSULA DE YUCATAN	139626
XI CUENCAS CERRADAS DEL NORTE	269400
XII LERMA	89332
XIII VALLE DE MEXICO	22470
TOTAL	1967948



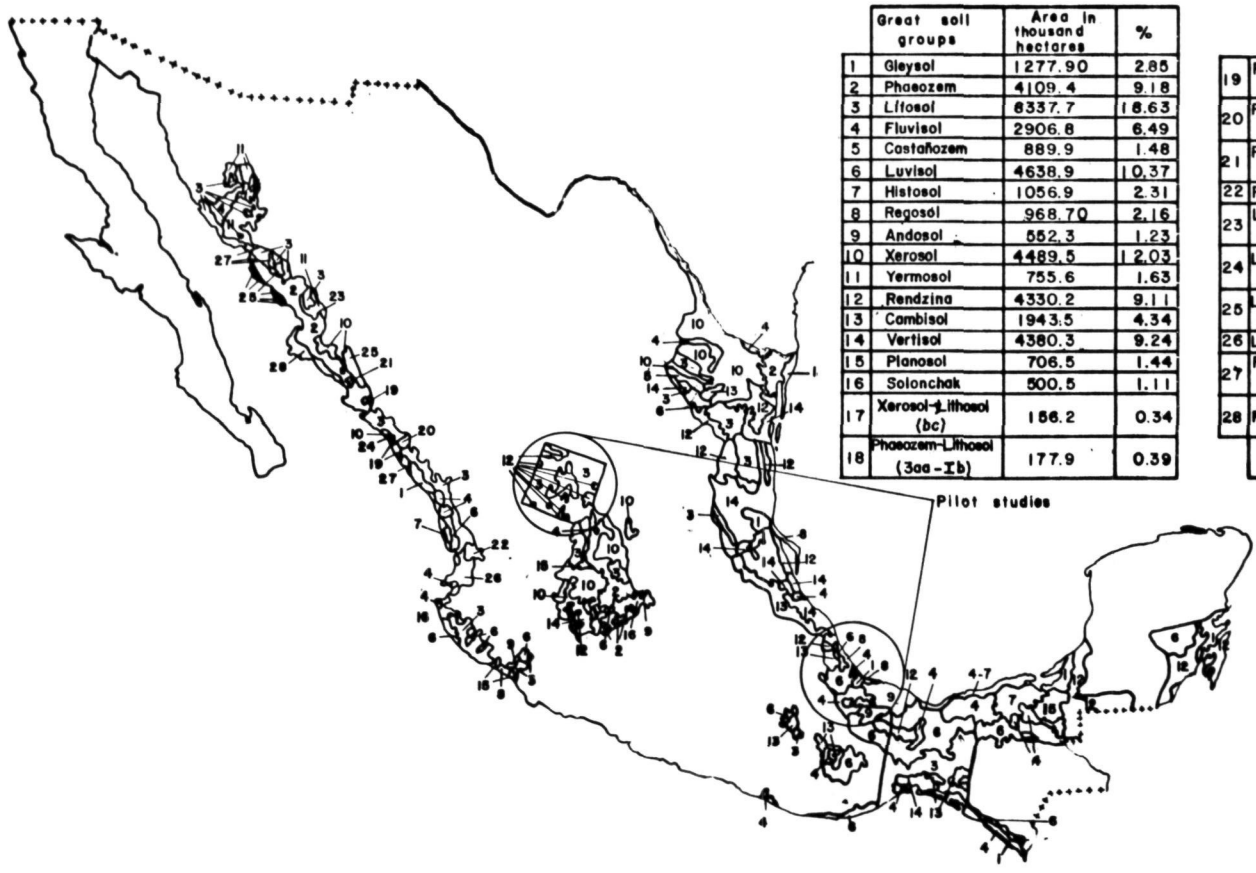
	LAND USE	AREA IN THOUSAND Ha	% OF TOTAL TERRITORY
	IRRIGATED CROPLAND	4,178.91	2.12
	FLAT RAINFED CROPLAND	18,050.14	9.17
	STEEP RAINFED CROPLAND	9,935.88	5.05
	RANGE AND GRASS LAND	12,290.50	6.24
	OTHER USES (Wood land, tropical forest, shrub land)	98,470.0	50.07
	CLOUD COVERED	2,875.36	1.47
	AREAS IN PROCESS OF STUDY	50,913.13	25.88
	TOTAL	196,713.92	100.00

Figure 2-A Present land use study in Mexico

Figure 3. Schedule of activities in the present land use study

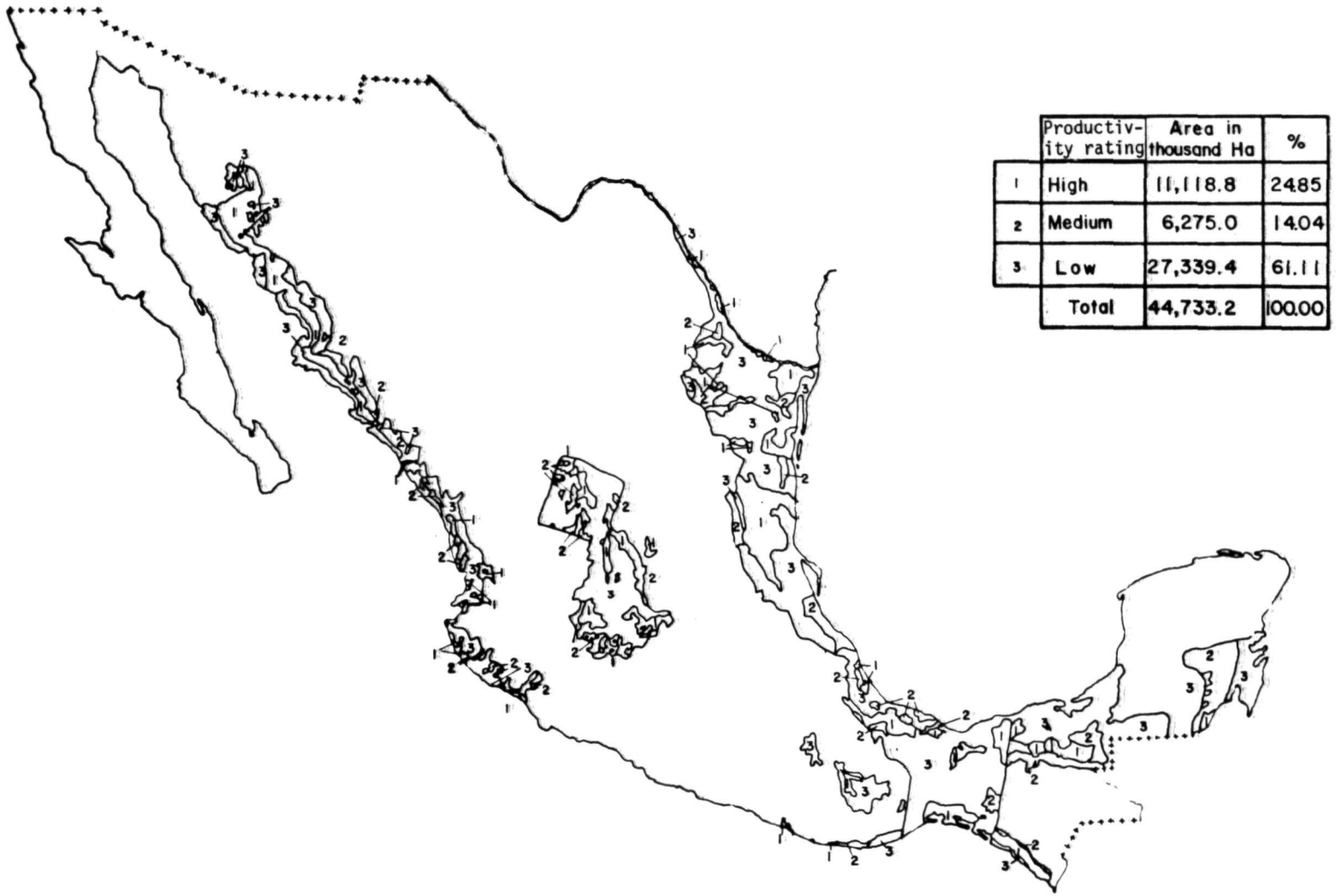


1/ A total distance of 13,500 Km was covered by plane. Ground truth covered 12,500 Km, sampling 4,000 points.



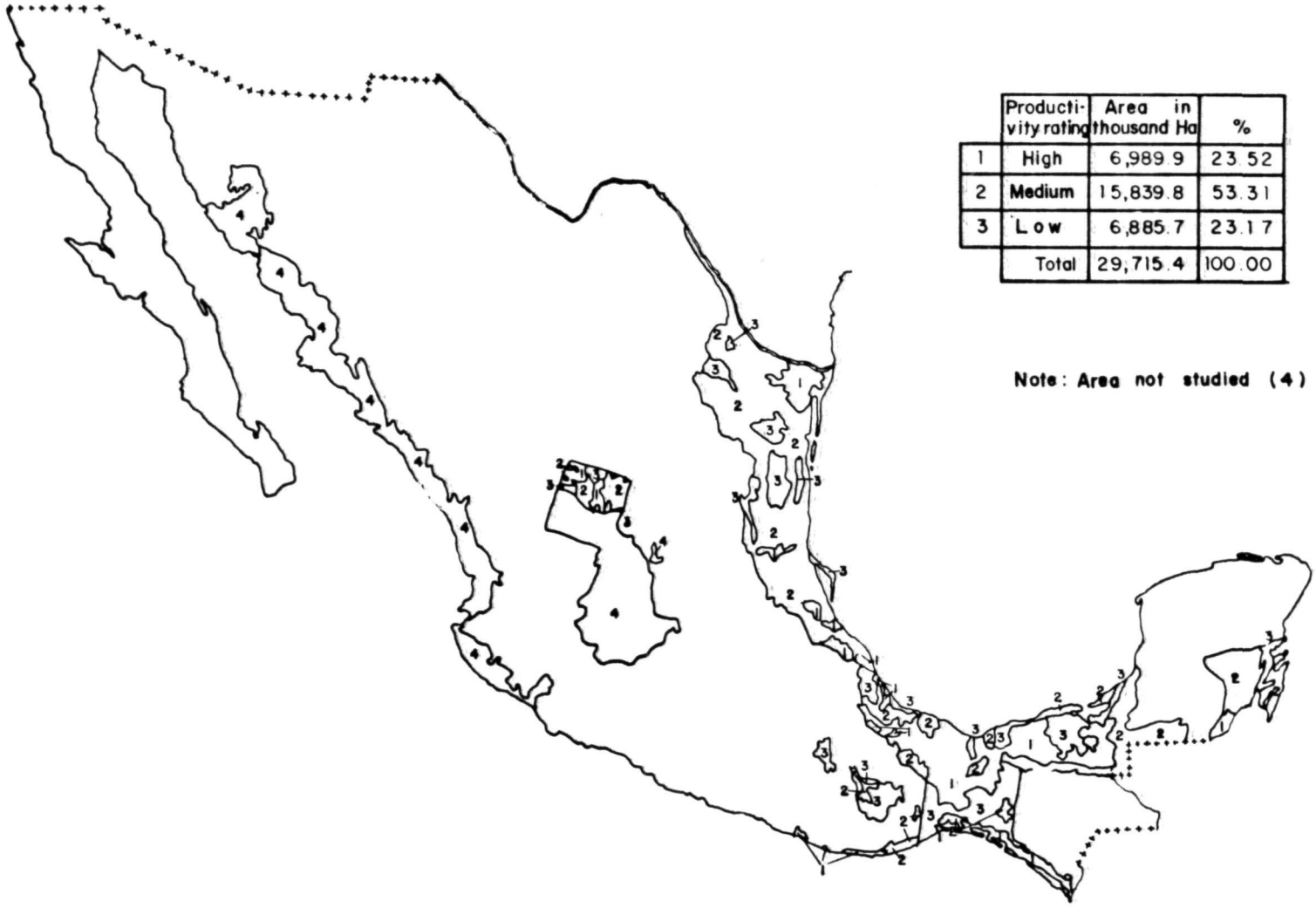
	Great soil groups	Area in thousand hectares	%
1	Gleysol	1277.90	2.85
2	Phaeozem	4109.4	9.18
3	Litosol	8337.7	18.63
4	Fluvisol	2906.8	6.49
5	Castañozem	889.9	1.48
6	Luvisol	4638.9	10.37
7	Histosol	1056.9	2.31
8	Regosol	968.70	2.16
9	Andosol	552.3	1.23
10	Xerosol	4489.5	12.03
11	Yermosol	755.6	1.63
12	Rendzina	4330.2	9.11
13	Cambisol	1943.5	4.34
14	Vertisol	4380.3	9.24
15	Planosol	706.5	1.44
16	Solonchak	500.5	1.11
17	Xerosol-Lithosol (bc)	156.2	0.34
18	Phaeozem-Lithosol (3aa-Ib)	177.9	0.39
19	Phaeozem-Lithosol (3a-Ib)	177.0	0.39
20	Phaeozem-Lithosol (3a-Ic)	151.0	0.33
21	Phaeozem-Lithosol (2a-Ibc)	104.4	0.23
22	Phaeozem-Vertisol	134.6	0.30
23	Lithosol-Phaeozem (b-3a)	310.9	0.69
24	Lithosol-Phaeozem (c-3a)	225.0	0.50
25	Lithosol-Phaeozem (c-2b)	331.0	0.74
26	Lithosol-Luvisol	458.2	1.02
27	Fluvisol-Vertisol - - -	57.0	0.12
28	Regosol-Solonchk	605.2	1.35
	Total	44,733.2	100.00

Figure 4 Potential land use studies in Mexico. Great soil groups and associations. Preliminary results.



	Productivity rating	Area in thousand Ha	%
1	High	11,118.8	24.85
2	Medium	6,275.0	14.04
3	Low	27,339.4	61.11
	Total	44,733.2	100.00

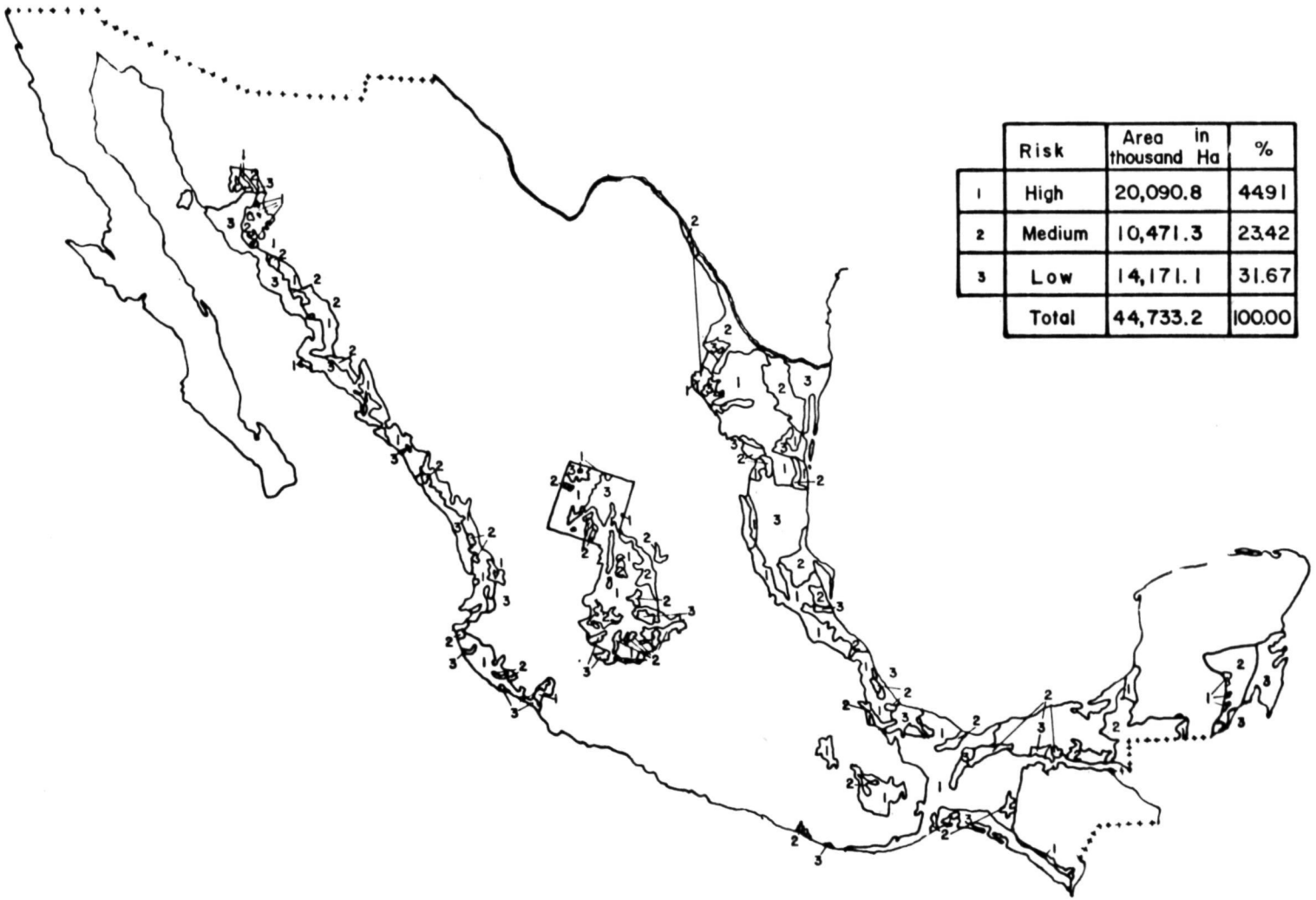
Figure 5 Potential soil productivity for agriculture



	Productivity rating	Area in thousand Ha	%
1	High	6,989.9	23.52
2	Medium	15,839.8	53.31
3	Low	6,885.7	23.17
	Total	29,715.4	100.00

Note: Area not studied (4)

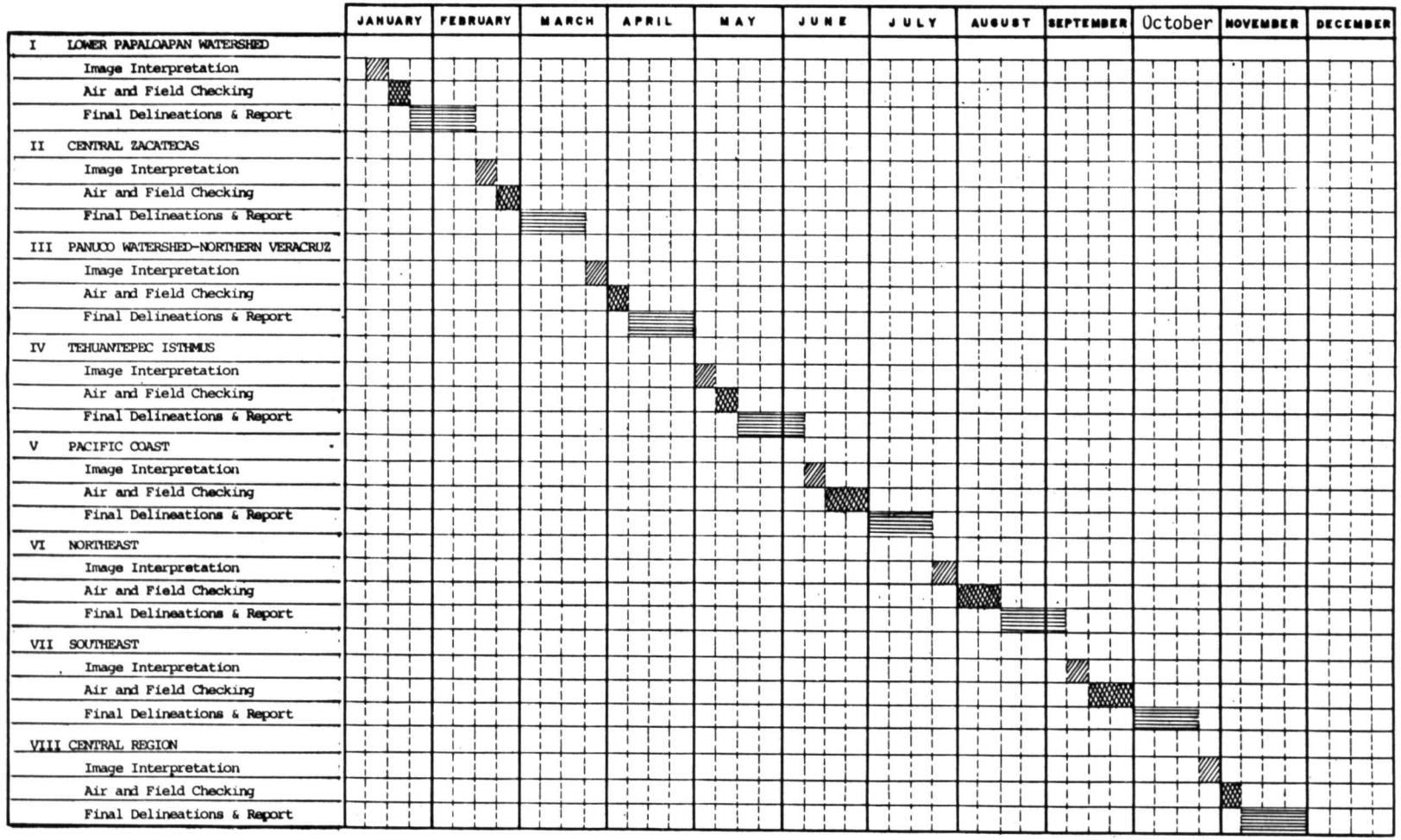
Figure 6 Potential soil productivity for grass



	Risk	Area in thousand Ha	%
1	High	20,090.8	4491
2	Medium	10,471.3	23.42
3	Low	14,171.1	31.67
	Total	44,733.2	100.00

Figure 7 Water Erosion risk

FIG.-8 SCHEDULE OF ACTIVITIES FOR THE POTENTIAL LAND USE STUDY



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LAND USE CLASSIFICATION IN BOLIVIA

By Carlos E. Brockman, Director, Bolivian LANDSAT Program, GEOBOL, La Paz, Bolivia, and William G. Brooner, Earth Satellite Corporation, Consultant to the United Nations Development Program for the Bolivian LANDSAT Program

ABSTRACT

The Bolivian LANDSAT Program is an integrated, multidisciplinary project designed to provide thematic analysis of LANDSAT, SKYLAB, and other remotely sensed data for natural resource management and development in Bolivia. Among the first requirements in the program has been the development of a Legend, and appropriate methodologies, for the analysis and classification of present Land Use based on landscape cover.

The Land Use Legend for Bolivia consists of approximately 80 categories in a hierarchical organization which may be collapsed for generalization, or expanded for greater detail. The categories, and their definitions, provide for both a graphic and textual description of the complex and diverse landscapes found in Bolivia, and are designed for analysis from LANDSAT and other remotely sensed data at scales of 1:1,000,000 and 1:250,000.

The Land Use Legend and map products are designed to meet the data needs and requirements of multiple user groups in Bolivia, including the Ministry of Agriculture, Military Geographical Institute, Corporacion Minera de Bolivia, Yacimientos Petroliferos Fiscales Bolivianos, National Statistics Institute, Bolivian Geological Survey, regional planning agencies, etc., each of which have participated in the Legend and procedures development.

Procedures and example products have been developed, as described and illustrated, for the systematic analysis and mapping of present Land Use for all of Bolivia. This project, the first of its kind in Bolivia, is presently underway for areas of image availability.

The program is designed to provide detailed 1:250,000 Land Use Maps for the Country of Bolivia within the next year. This schedule, however, is presently hampered by the lack of sufficient cloud free and multi-date LANDSAT imagery for extensive areas in Bolivia. The current effort is based on the anticipation that LANDSAT-2 will provide the needed image requirements for this program so that effective resource management and development applications may proceed from the various user groups.

INTRODUCTION

The Bolivian Government, keenly interested in obtaining basic and necessary information about its natural resources, is actively using satellite remotely sensed data. To provide a sound focus and coordination of technical leadership and management to this effort, the Bolivian LANDSAT Program was created within the Bolivian Geological Survey (GEOBOL). Also participating in the Program, in a vigorous and active work program, are investigators and scientists from: other offices within the Geological Survey; the Bolivian Petroleum Company (YPFB); the Mineral Corporation of Bolivia; the National Statistic Institute (INE), Census Office; the Military Geographic Institute (IGM), the Ministry of Agriculture & Rural Affairs, and the various regional planning agencies. The present work program includes investigations in regional geology, petroleum geology, mineral geology, existing land use, cartography, soils, and forestry.

At the present time, Bolivia has conventional aerial photographic coverage, acquired over an extensive time period, for only approximately sixty (60) percent of the country. This has inhibited the preparation of various thematic maps necessary to carry out a program of comprehensive, definitive national planning and development at the regional and subregional scales. For this reason, images from LANDSAT and SKYLAB are of great value and are being intensively analyzed for multi-disciplinary objectives. With these satellite image data, the various Bolivian investigators are able to prepare the thematic maps and analyses necessary to carry forward national resource planning and development programs in a relatively short time frame. Consider, for example, the following: (a) various geological analyses may be, and are being, updated and revised, and used in the selection of new areas for mineral and petroleum exploration; (b) agriculturalists are obtaining basic information not only on the distribution of agricultural activities and forest types, but also on the characteristics and limitations of soils and land capability for agricultural expansion and colonization development, and forest inventory data basic to that resource's exploitation and development planning; (c) in 1973 the Bolivian Military Geographic Institute published a nationwide topographic map at 1:1,000,000 scale, using LANDSAT images; and (d) completion of the present effort to prepare a general hydrographic map and analysis will permit Bolivian investigators to determine the extent and influence of the large hydrologic basins and the quantification of the sub-basins and watersheds. This information, when combined with other data in adequate forms, will permit the selection of the most appropriate areas for utilizing water resources for hydroelectric power and irrigation development. Further, the above application examples have not taken into consideration the inventory preparation and application of existing land use data which is the purpose of the present report.

Considering its basic and fundamental importance to a variety of integrated applications and analyses, the Bolivian LANDSAT Program has proceeded with the preparation of the first national legend, and inventory, of existing land use based on land cover and landscape analysis. Attributes for all of the natural and cultural landscapes presently existing throughout the country are being studied at a regional and sub-regional scale. The Land Use Legend contains approximately eighty (80) categories for application at various scales. Preliminary tests, analyses, and legend revisions have demonstrated that the legend categories can be used in the analyses of LANDSAT and SKYLAB multitemporal images, along with available supplementary information which can be used for the Land Use Inventory in Bolivia.

The Land Use Inventory of Bolivia is being compiled at two scales, 1:1,000,000 and 1:250,000, each with appropriate levels of classification detail. The Legend, its development and its characteristics, are discussed in the next section of this report. This is followed by a brief synthesis of the techniques used for the present land use analysis and a description of the cartographic products being prepared.

The land use maps permit the location and spatial distribution, quantification, and analysis, at a sub-category level of detail, of areas that have rangeland, forest, cultivation, wetlands, water, barren, permanent snow and ice, and tundra cover, as well as areas of urban places and settlements. In addition, the land use maps can, and will, be applied in many ways and by numerous agencies and other user organizations, providing basic information for the planning and development of the country. Some of these potential applications are described in the final section of this report, as prepared by cognizant participants from the respective agencies to the Bolivian LANDSAT Program.

In summary, the Land Use Legend presented in this report represents a classification of Bolivian landscapes which meets the needs of various users for natural resource information and provides information which can be accurately obtained using proven satellite image analysis techniques and procedures. The Legend is capable of further refinement on the basis of additional data, and is capable of varied use and application. It is believed that this Legend, subject to modification and revision, provides the basis for standardized regional and national analysis and mapping of actual land use in Bolivia.

THE BOLIVIAN LAND USE LEGEND

The present use of land, or its present cover - whether a natural landscape or one modified by man's activities on the land - is a significant characteristic for resource planning, management, and development. The term "land use", however, is a difficult concept because there are different perspectives in the classification process as well as considerable diversity of opinion about what constitutes "land use". It is important to distinguish, for example, between potential land use and actual land use. The former requires a complex analysis of many physical characteristics of the land, including slope, soils, vegetation, etc., to determine the land's suitability for specific activities, i.e., crop cultivation. Actual land use, however, refers to the present use of the land, to a description of the present landscape characteristics without regard to its potential or future uses. The Land Use Legend described in this report refers to the latter, actual land use, and is one of the multiple inputs in the potential land use analysis process.

Anderson (1971)* discusses some of the conceptual issues important in developing a land use classification legend. "One concept that has much merit is that land use refers to 'man's activities on land which are directly related to the land (Clawson and Stewart, 1965)'. Land cover, on the other hand, would describe 'the vegetational and artificial constructions covering the land surface' (Burley 1961)". Thus the distinction between economic activity on the land, and the land cover, is drawn in describing land use, even though some economic activities of man are directly related to the land cover, such as agricultural activities and the resulting landscape patterns. In the Bolivian land use legend, land cover is the primary basis of classification and subsequent description and analysis.

Bolivia is a country of complex and diverse landscapes, from mountain tundra and glaciers to tropical rainforests and savannas. A land use classification legend must not only be specific and complete over the entire range of existing landscapes, but must also serve the needs and applications of multiple and diverse users in Bolivia. Although definitions have been developed, as presented in Appendix A, it is recognized that in almost any classification system it is often difficult to find clearly, unambiguously defined classes. Actual land use is no exception and most difficult problems can be encountered, particularly in areas of landscape or land cover transition.

For example, it may seem simple to draw a line on a map separating land and water, until we consider the presence of marshes with various kinds of plant cover. Further, some areas may appear to qualify for more than one category, or the category may change on a seasonal basis, such as seasonally wet areas. The definitions which are provided with each category in the land use legend are designed to provide guidelines to the land use analyst in establishing boundary and classification decisions. They also provide the land use data user with a better means of interpreting and using the land use data. Decisions that may seem at times arbitrary must be made; however, it is desired that if the categories are briefly explained, the land use analysis, inventory, and mapping process can be repeated in a systematic manner.

The Land Use Legend has been designed for the categorization of all parts of Bolivia, and the definitions are specific to the Bolivian landscape and the development of regional and national coverage maps at 1:250,000 and 1:1,000,000 scales. By relying principally on information derived from LANDSAT and SKYLAB images, with supplemental use of existing maps, aerial photography, and other data, the resulting maps will show actual land use information that is uniform in date, scale, and categorization.

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* See Anderson, J.R. (1971), Land Use Classification Scheme for Use With Remote Sensor Data, U.S. Geological Survey, Circular 671, Washington, D.C.

The Land Use Legend is hierarchical in design, as shown on Table 1. It may be expanded to include more detailed categorization at larger scales, and at the same time remain compatible with more generalized maps. (It is noted that the design of the Land Use Legend for Bolivia has many similarities to the classification system proposed for the United States of America, by Anderson et. al., 1971. Although Anderson's work certainly guided its structure, the contents of the Bolivian Legend are specific to the Bolivian environment and the resource inventory needs of the various users in Bolivia).

The Land Use Legend is multi-disciplinary in both its information content and its application. Similarly, the legend is the product of a multi-disciplinary team which, combined, included expertise in: the geography of Bolivia, its natural and cultural environments and landscapes; the development and application of land use data for resource management and development; the capabilities of LANDSAT, SKYLAB, and other remote sensing systems as sources of land use and natural resource information; and specialists in various resource related disciplines, including geology, agriculture, forestry, soils, regional planning, and cartography, etc. Using a multi-disciplinary, team approach, the group applied several criteria in designing the Land Use Legend, as follows:

1. The classification legend of actual land use must be specific to all types of landscapes and environments of Bolivia.

2. The map and other data products for actual land use must provide information which, when combined with other resource information, will directly meet information needs and requirements of multiple users in Bolivia.

3. Classification of various legend categories should permit vegetation and other types of land cover to be used as surrogates for the categories of actual land use.

4. The Legend should be designed for primary use of satellite imagery interpretation, including both LANDSAT and SKYLAB images as available, acquired at different times during the year.

5. In the hierarchical organization of categories, Level I categories should be interpretable and mappable at an image and map scale of 1:1,000,000; Level II and III categories should be interpretable and mappable at an image and map scale of 1:250,000.

6. The categories must be collapsible for map generalization.

7. Sub-categories, such as some Level III as well as additional future sub-categories, should be determinable through the effective use of aerial and ground reconnaissance surveys, aerial photographs, and other supplemental information.

8. The Legend and analysis procedures must be designed to enable repeatable results from one image interpreter to another, and from one time period to another.

9. The quality (accuracy) of the land use information interpreted from the satellite images, with supplemented data, must be comparable or superior to that obtained by other methods.

10. Mimimum map units, at 1:250,000 scale, should generally be 150 hectares for area features, and 125 meter widths for linear features; however, features smaller than these minimum units may be shown on the Land Use Maps, particularly when based on supplemental information.

It is noted that not all categories in the Land Use Legend may be interpreted from satellite imagery with equal reliability. In many cases, particularly for some Level II and Level III categories, supplemental data will be required and should be used effectively. Supplemental data, in this instance, includes aerial photographs, aerial and ground reconnaissance surveys, existing maps, and other data and records. Image analysis should also include multi-date imagery, particularly where seasonal or other temporal changes may assist in correct category identification.

LAND USE MAPPING PROCEDURES

The purpose of this section is to provide a brief summary of the procedures and techniques used in the preparation of the Bolivian land use maps. This discussion is not a procedures guideline, but rather a synthesis intended to provide readers and map users with a succinct background of factors which influence the map's characteristics and applications. The procedures have been standardized wherever possible in order to attain a consistent and accurate land use map series; it is recognized, however, that image interpretation often requires subjective and judgmental decisions by interpreters of varying background, experience, and skill.

It is planned that the Bolivian land use map series will be published at two scales, 1:1,000,000 and 1:250,000. These scales correspond to topographic and other thematic maps prepared for Bolivia. The map preparation can be described by the following scenario:

1. A preliminary interpretation is made on 1:1,0000,000 LANDSAT images at Level I detail of the Land Use Legend. The purpose of this exercise is to familiarize image interpreters with the region under study; identify areas of particular complexity or concern for which supplemental data will be required, and to identify and acquire available imagery, maps, and other supplemental information of the study area.

2. A detailed interpretation is made using 1:250,000 scale LANDSAT and/or SKYLAB imagery using all appropriate categories (Level III) of the Land Use Legend. During this analysis, all available multi-temporal imagery and supplemental information, including existing maps and aerial photographs, are utilized as appropriate to ensure accuracy and completion of the map detail. Field surveys are conducted to identify ambiguous areas and verify interpretations. The final, edited land use map, at 1:250,000 scale, constitutes a final product of the project.

3. Following completion of the 1:250,000 land use map, a revised 1:1,000,000 map is compiled, at Level II detail of the Land Use Legend, through the process of category aggregation of the larger scale data. This revised land use map also becomes a final product of the project.

The 1:1,000,000 scale Land Use Map series permits delineation of major landscape features and patterns, and provides a graphic analysis of the location and spatial relationships of landscape elements at a regional level. Bolivia is a country of complex and contrasting landscapes and environments; the differentiation of these landscapes at 1:1,000,000 scale is considered very important and useful for both analytical and display applications.

The 1:250,000 scale Land Use Map series permits additional delineation and classification of landscape features and patterns described in the legend. The cartographic products graphically portray location and spatial distributions at a sub-regional level. This product will be the scale of principal application and will also enable the accurate selection of areas requiring further analysis and/or greater detail to meet the information requirements of a specific application.

Interpretation Techniques

The interpretation techniques employed in this project are similar to those of conventional photo-interpretation and appropriate modifications for satellite image analysis. To date, most analyses have been based on multiband black and white print products, supplemented with (a) color composite transparencies at 1:1,000,000 scale using Diazo processing, and (b) color composites produced by an I^2S Addcol Viewer (Additive Color Projection Viewer). Both multi-spectral and multi-temporal combinations are used extensively, particularly for the discrimination and analysis of vegetative color patterns and seasonal and/or temporal landscape conditions. A Zoom-Transfer Scope is also available and used, particularly in the transfer of detailed multi-temporal and vegetative color interpretations from the 1:1,000,000 scale color composites to the 1:250,000 scale base map prints. At the present time, the more intensive use of large scale color composite and color enhanced image prints is being analyzed with ten (10) LANDSAT and two (2) SKYLAB scenes, and a color photographic processing facility is under construction.

Supplemental Data

A variety of supplemental information are used in the detailed analysis of the satellite images. This data includes existing aerial photography, maps, and textual and statistical information.

Aerial photography is presently available and current for approximately sixty (60) percent of the country, most commonly at approximately 1:40,000 scale on black and white film. In addition, the Bolivian LANDSAT Program has acquired an I^2S multi-spectral camera, mounted in a Cessna 402 aircraft. This system is used principally for large and medium scale aerial photographic acquisition and to date has been flown in the altiplano and Santa Cruz regions. And finally, an effort is underway to acquire and catalogue small format (35 mm) color oblique aerial photographs obtained at medium and high altitudes. When indexed, these photographs will provide a valuable source of supplemental information as has already been demonstrated in several regions.

A variety of thematic maps, at varying scales, are available for various regions of Bolivia and contain useful supplemental information. The map types include topographic maps at 1:50,000, 1:250,000, and 1:1,000,000 scales, hydrological, geological, and geomorphological maps compiled by satellite interpretation as well as conventional means and vegetation, soils, and ecological maps. The principal sources of these data are the Ministry of Agriculture, the Military Geographical Institute, the Bolivian Geological Service, the National Meteorological and Hydrological Service, the Bolivian LANDSAT Program, and the University of Major de San Andres.

Field Surveys

Field surveys are conducted both during the detailed 1:250,000 scale analyses, as necessary, and upon completion of the interpretation effort. The presently recommended procedure for the field surveys involves the use of low and medium altitude aircraft observations, particularly in the extensive regions of limited ground accessibility.

The objectives of the aerial field surveys is (a) to enable the image interpreters to acquire a greater knowledge of the study region that will be beneficial to multiple analyses and evaluations of the natural resources; and (b) to compare, confirm, and correct delineations and interpretations of the LANDSAT images. In addition, oblique aerial photographs are acquired of significant features in the study area.

During the flight planning for the field surveys, transectoral flight lines are drawn to cover a representative range of mapped land use units, areas of particular

significance, and areas of question or ambiguity. The flight lines, with distance and cardinal heading, on 1:1,000,000 scale LANDSAT prints which are then used as a pilotage navigation aid. This technique has been tested and demonstrated to be particularly effective in regions lacking accurate charts and facilities for aircraft navigation.

Classification Scheme Expansion for Special Analyses: An Urban Example

An important characteristic of the Land Use Legend is the ability to expand the hierarchical classification scheme to Level IV or greater detail to meet particular analysis applications or information needs. An example is in the urban categories of the Legend and the information needs of urban planners, the Census Office, and others who find a Level III detail at 1:250,000 scale inadequate. Level IV information relies almost exclusively on supplemental data, such as aerial photography, and field surveys.

Upon reviewing the Land Use Legend at Level III in the urban categories, Bolivian urban planning and Census Office investigators preliminarily identified the Level IV categories of interest, shown on Table 2. Existing black and white aerial photographs of the City of La Paz were available at scales of 1:40,000, 1:25,000, and 1:8,000. Land Use maps, at Level IV detail were prepared at each scale using conventional photo-interpretation techniques and procedures, and the results were compared and evaluated in terms of suitability of the Legend and scales. It was determined that the most optimal scale for the Level IV Legend and diverse user needs was approximately 1:25,000.

APPLICATIONS

The Land Use Legend and methodologies were developed by a multidisciplinary team of Bolivian investigators representing a variety of user agencies. Each agency has unique programs and responsibilities which place varying requirements on information need and its content. Of considerable importance is the effort to develop basic information which has broad application and is responsive to the varied users requirements. Such an objective can only be satisfied through time and experience, and with an adaptation to new forms of data derived from developing technologies.

Following the development of preliminary products using the Land Use Legend and methodologies described in previous sections, each "user group" was asked to briefly consider the merits of the Legend and map products in terms of their own programs and information requirements. While each had unique applications, many were very similar, reflecting a universal lacking of consistent natural resource and landscape information throughout the country. To this, the systematic analysis of LANDSAT and SKYLAB imagery has provided immeasurable benefits.

The following discussion briefly summarizes the applications of the land use products preliminarily identified by "users" representing the Ministry of Agriculture, the Census Office of the National Statistics Institute, the Geological Survey, the Military Geographic Institute, and the Ministry of Planification and Coordination.

Ministry of Agriculture

Land use maps at a scale of 1:1,000,000 were evaluated and determined to be of significant information value in several disciplinary areas: (a) the analysis of existing land use, particularly when combined with other resource data, can be effectively used to better identify areas of potential colonization and development based on land capability; (b) the extent and type of forest resources, previously poorly documented, are well delineated and provide basic data for analyses of wildlife habitats and commercial forest product exploitation; (c) areas of extensive erosion surfaces are identified, providing basic planning information for regional soil conservation programs;

(d) areas of natural pastures are identified and may be analyzed to determine better allocation of rangelands for livestock use; (e) the accurate determination of river and lake locations is of value to fisheries analysis and their exploitation, and (f) areas of saline soils and salt flats may be broadly defined and analyzed as appropriate to the planning and allocation of agricultural programs where these landscape conditions pose limitations to their use.

Census Office, National Statistics Institute

The Census Office maintains a locality of registry and mapping system for population characteristics throughout the country. A national census will be conducted next year and will acquire data on the social, economic, and geographic composition of the population. The regional land use maps, even at a very general level of detail, provide several important applications, particularly in the census planning phases. These range from the delineation of areal collection units, regional accessibility and communication based not only on road network but river courses as well, and the regional analysis of landscape features indicating the presence of humans. The use of supplemental information can accurately verify the locations of human settlement and the delineation of urban areas and the urban fringes as areas in transition. In addition, the Land Use maps provide a basis for the planning of an agricultural census in Bolivia.

Geological Survey

The Land Use maps provide a useful complementary data source to geological, and particularly geomorphological, analyses of LANDSAT and SKYLAB images. For example, landscapes characterized by exposed rock outcrops, sand dunes, and saline zones are important units for geological analysis. Vegetation, either natural or artificial (such as agricultural cultivation) can be an important surrogate of surficial materials and characteristics. The analysis of drainage networks also provide inferences of surface material, geological structure, and land forms.

Military Geographical Institute

The Military Geographical Institute (IGM) is the official cartographic entity in Bolivia. It has already demonstrated the use of LANDSAT imagery in the compilation of a 1:1,000,000 topographic map series in 1973. The Land Use maps are of IGM use in the delineation of urban, rural, and uninhabited areas, in the comparison of changes in river courses and the shape and size of lakes and lagoons, and in the determination of seasonally and permanently flood areas. In addition, the maps provide a basic resource for planning field work in conjunction to both topographic mapping programs as well as special purpose projects where a knowledge of general terrain characteristics and cover is beneficial.

Ministry of Planification and Coordination

The Ministry of Planification and Coordination is responsible for regional planning programs in Bolivia. The Land Use maps enable descriptions and analyses of physical, economic, and social characteristics in the plan development process as well as a diagnosis of probable future changes and developments. Additional studies can provide an evaluation of fiscal and technical resources available in both public and private sectors.

CONCLUSIONS

The previous discussion has presented a relatively recent application development for LANDSAT and SKYLAB imagery in Bolivia -- the development of a national Land Use Legend and methodologies for the preparation of cartographic products. Several points have been made, summarized as follows:

(1) LANDSAT and SKYLAB images can be used in the preparation of Actual Land Use maps in different scales to meet both national and regional objectives;

(2) It is necessary to use multi-temporal images in order to obtain the desired results;

(3) It has been concluded that the most optimal map and image scales for the Land Use analyses are 1:1,000,000 and 1:250,000;

(4) The general organization of the Land Use Legend was strongly guided by the previous work of James R. Anderson of the U.S. Geological Survey, and has broad applicability to diverse regions of the world at its more generalized levels. The detailed categories, however, at Levels III and IV are specific to the Bolivian environment;

(5) At the present time, the Land Use Legend must be considered preliminary; revisions will occur as the result of further experience in the LANDSAT and SKYLAB investigations as well as the applications of the participating "user" agencies. The present form of the Legend, however, provides a structure for a comprehensive and nationwide land use analysis for the first time in Bolivia.

TABLE 1

BOLIVIAN LAND USE LEGEND

LEVEL I	LEVEL II	LEVEL III
1 RANGELANDS Tierras con Pastizales	11 High Rangelands Pastizales de Altura	111 Wet high rangelands Pastizales de alturas húmedos 112 Temporally wet high rangelands Pastizales de altura temporalmente húmedos 113 Dry high rangelands Pastizales de altura secos 114 Dry high rangelands affected by salinity Pastizales de altura secos afectados por salinidad
	12 Intermediate Altitude Rangelands Pastizales de Altura intermedia	121 Wet intermediate altitude rangelands Pastizales de alturas intermedias húmedos 122 Temporally wet intermediate altitude rangelands Pastizales de alturas intermedias húmedos temporalmente 123 Dry intermediate altitude rangelands Pastizales de alturas intermedias secos
	13 Lowland Rangelands Pastizales de Tierras Bajas	131 Wet savannas Sabanas húmedas 132 Mesophytic savannas Sabanas mesofíticas 133 Xerophytic savannas Sabanas xerofíticas 134 Prairie lands Praderas
2 FOREST LANDS Tierras con Bosques	21 Deciduous Forests Bosque Deciduo	211 Dune deciduous forests Bosque deciduo de dunas 212 Lowland deciduous forests Bosque deciduo de tierras bajas 213 Galleria deciduous forests Bosque deciduo de galería 214 Piedmont deciduous forests Bosque deciduo de pie de monte 215 High hills deciduous forests Bosque deciduo de colinas altas 216 Montane deciduous forests Bosque deciduo de montañas

		217 Valley deciduous forests Bosque deciduo de valles
	22 Evergreen Forests Bosque Siempreverde	221 Dune evergreen forests Bosque siempreverde de vegas 222 Lowland evergreen forests, not flooded Bosque siempreverde de tierras bajas no inundables 223 Galleria evergreen forests Bosque siempreverde de galería 224 Piedmont evergreen forests Bosque siempreverde de pie de monte 225 High hills evergreen forests Bosque siempreverde de colinas altas 226 Montane evergreen forests Bosque siempreverde de montañas 227 High mountain evergreen forests Bosque siempreverde de alta montaña
	23 Transition Forests Bosque de transicion	231 Dune transition forests Bosque de transición de vegas 232 Lowland transition forests, not flooded Bosque de transición de tierras bajas no inundables 233 Galleria transition forests Bosque de transición de galería 234 Piedmont transition forests Bosque de transición de pie de monte 235 High hills transition forests Bosque de transición de colinas altas
3 CULTIVATED LANDS **Tierras Cultivados**	31 Cultivation in High Altitudes and the Altiplano Cultivos en Altura y Altiplano	311 Intensive cultivation Cultivos intensivos 312 Extensive cultivation Cultivos extensivos 313 Undifferentiated cultivation and pastures Cultivos y pastizales indiferenciados
	32 Cultivation in Intermediate Altitudes Cultivos en Alturas intermedias	321 Intensive cultivation Cultivos intensivos 322 Extensive cultivation Cultivos extensivos 323 Undifferentiated cultivation and pastures Cultivos y pastizales indiferenciados

	33 Lowland Cultivation Cultivos de alturas bajas	331 Intensive cultivation Cultivos intensivos 332 Extensive cultivation Cultivos extensivos 333 Undifferentiated cultivation and pastures Cultivos y pastizales indiferenciados
4 WETLANDS Tierras Húmedas	41 High Altitude Vegetated Wetlands Tierras Húmedas de Zonas Atlas con Vegetación	411 Permanent wetlands Tierras húmedas permanentes 412 Temporary wetlands Tierras húmedas temporales
	42 Lowland Vegetated Wetlands Tierras Húmedas de Zonas Bajas con Vegetación	421 Permanent wetlands Tierras húmedas permanentes 422 Temporary wetlands Tierras húmedas temporales
	43 Non-Vegetated Wetlands Tierras Húmedas sin Vegetación	
5 WATER Agua	51 Lakes Lagos	
	52 Small Lakes (including ponds) Lagunas	521 Permanent lakes Lagunas permanentes 522 Temporary lakes Lagunas temporales
	53 Rivers Ríos	531 Permanent rivers Ríos permanentes 532 Temporary rivers Ríos temporales
	54 Reservoirs Reservorios	
6 BARREN LANDS Tierras Eriales	61 Salt Flats Salar 62 Playas and Dunes Playas y Dunas 63 Exposed Rock Zonas Rocosas 64 Surface mines and quarries Desmontes mineros y canteras 65 Saline Lands Tierras Salinas	

	66 Badlands Mal País (Badlands) 67 Other Otras	
7 Permanent Snow and Ice Nieve y Hielo Permanente	71 Fields with Permanent Snow Campos con Nieve Permanente 72 Glaciers Glaciares	
8 Tundra Tundra	81 Wet tundra Tundra Húmeda 82 Dry Tundra Tundra Seca	
9 Urban Areas Areas Urbanas	91 Cities Cindades 92 Towns and Villages Pueblos	
	93 Transportation and Communication Facilities Transportes y Communicaciones	931 Airports and landing fields Campos de aterrizaje 932 Railroads and roads Carreteras y caminos 933 Others (pipelines, powerlines, etc.) Otros (oleductos, líneas de energia electrica, etc.)

TABLE II

EXPANDED LEGEND EXAMPLE FOR CITIES

91 Cities
Ciudades

- 911 Residential Areas
  Areas residenciales
  - 9111 Single Unit residential
    Unidad simple separada
  - 9112 Multi-unit residential
    Unidad múltiple conjunto
- 912 Commercial Areas
  Areas comerciales
- 913 Industrial Areas
  Areas Industriales
- 914 Urban Transportation
  Transportes Urbanas
  - 9141 Roads and Streets
    Caminos y avenidas
  - 9142 Railroads
    Ferrocarriles
  - 9143 Airports
    Aeropuertes
  - 9144 Canals & Pipelines
    Agua Canalizada y Oleoductas
- 915 Institutional
  Institucionales
  - 9151 Schools
    Escuelas
  - 9152 Churches
    Iglesias
  - 9153 Public Buildings
    Edificios públicos
  - 9154 Military
    Militares
  - 9155 Hospitals and clinics
    Hospitales y clínicas
- 916 Mixed
  Areas mixtas indiferenciadas
- 917 Open Spaces
  Espacios Abiertos
  - 9171 Parks
    Pargues
  - 9172 Recreational areas
    Areas de recreación
  - 9173 Other open spaces
    Otros espacios abiertos

APPENDIX A

LAND USE LEGEND DEFINITIONS

Bolivian LANDSAT Program
Servicio Geologico de Bolivia
La Paz, Bolivia

LAND USE LEGEND DEFINITIONS

1 RANGELANDS

Areas, either natural or influenced by man, where grassy or other herbaceous forage species predominate; included are the high rangelands (altiplano), intermediate altitude rangeland zones, and lowland areas (savannas and prairies).

11 High Rangelands

Areas of natural pasture/range cover, located above 3,500 meters altititude MSL.

111 Wet high rangelands
Areas of natural pasture/range cover with soils that remain wet the major part of the year.

112 Temporally wet high rangelands
Areas of natural pasture/range cover with temporary (seasonal) flooding.

113 Dry high rangelands
Areas of natural pasture/range cover developed in dry environmental conditions, characterized by shrubby vegetation.

114 Dry high rangelands affected by salinity
Areas of natural pasture/range cover, generally of limited vegetation growth due to salinity.

12 Intermediate Altitude Rangelands

Areas of natural pasture/range cover, located between 1,500 and 3,500 meters MSL.

121 Wet Intermediate Altitude Rangelands
Areas of natural pasture/range cover with soils that remain wet the major part of the year.

122 Temporally wet intermediate altitude rangelands
Areas of natural pasture/range cover with temporary (seasonal) flooding.

123 Dry Intermediate Altitude Rangelands
Areas of natural pasture/range cover developed in dry environmental conditions, characterized by shrubby vegetation.

13 Lowland Rangelands

Areas of natural pasture/range cover, located below 1,500 meters MSL.

131 Wet Savannas
Areas with a combination of woody species (generally scattered trees) and predominantly grasses, with soils that remain wet the major part of the year.

132 Mesophytic Savannas
Areas with rangeland and trees that grow in regions of intermediate humidity.

133 Xerophytic Savannas
Areas of rangeland cover and/or a combination of lowland woody species, growing in dry environmental conditions and arid climates.

134 Prairie Lands (Praderas)
Areas of herbaceous vegetation lacking woody species as a result of dry environmental conditions and/or an arid climate.

2 FOREST LANDS

Lands predominantly covered by forest vegetation associations, capable of producing lumber and other forest products, with water resources and supporting wildlife.

21 Deciduous Forests
Forested areas in which all or most species types lose their leaves in the most prominent dry season or in the winter.

The subcategories of Deciduous Forests are based principally on physiographic regions, each one of which has its own characteristics.

211 Dune deciduous forests
212 Lowland deciduous forests
213 Galleria deciduous forests
214 Piedmont deciduous forests
215 High hills deciduous forests
216 Montane deciduous forests (on high mountain slopes)
217 Valley deciduous forests (in montane regions)

22 Evergreen Forests
Areas with a dense community of trees and shrubs, commonly in layers or stratums with abundant epiphytics. The tree-tops form a continuous cover in their different layers, the branches are generally established high and little branching out. The dominant trees do not lose their leaves at any time of the year, except at fruit bearing in the period of flowering. The subcategories of Evergreen Forests are based on physiographic regions where each one has its own characteristics.

221 Dune evergreen forests
222 Lowland evergreen forests which are not flooded
223 Galleria evergreen forests
224 Piedmont evergreen forests
225 High hills forests
226 Mountain evergreen forests
227 High mountain evergreen forests

23 Transition Forests
Forests where the dominant trees (25-50%) lose their leaves at one time of the year (deciduous).

The subcategories of Transition Forests are based on physiographic regions where each one has its own characteristics.

231 Dune transition forest
232 Lowland transition forests which are not flooded
233 Galleria transition forests
234 Piedmont transition forests
235 High hills transition forests

3 CULTIVATED LANDS

Areas commonly employed in agriculture, including cultivated land, rotated pastures, lands in fallow and temporarily idle; these lands are further described as areas with intensive cultivation*, areas with extensive cultivation**, and areas of mixed or undifferentiated cultivation and pastures***.

31 Cultivation in high altitudes and the altiplano
Areas with appropriate cultivation of high altitude zones, located above 3,500 meters MSL.

311 Intensive cultivation*
312 Extensive cultivation**
313 Undifferentiated cultivation and pastures***

32 Cultivation in intermediate altitudes
Areas of cultivation located between 1,500-3,500 meters MSL.

321 Intensive cultivation*
322 Extensive cultivation**
323 Undifferentiated cultivation and pastures***

33 Lowland cultivation
Cultivated areas located below 1,500 meters MSL.

331 Intensive cultivation*
332 Extensive cultivation**
333 Undifferentiated cultivation and pastures***

* Intensive cultivation - Areas subjected to cultivation with adequate technical application and frequent human labor-intensive activities; these areas produce at least one harvest per year, the ecological conditions determining the production.

** Extensive cultivation - Areas subjected to cultivation with medium to low technical application, of which human labor-intensive activities are limited; the soil may be left in fallow for one or more years, and for the most part the harvests are of low production.

*** Undifferentiated cultivation and pastures - Mixed agricultural areas, within which both cultivation and pastures are found in varying proportions.

4 WETLANDS

Areas of temporary or permanent water cover, with hydrophytic vegetation and sometimes characterized by deficient drainage (curiches and banados).

41 High altitude vegetated wetlands
Depressions subjected to different periods of flooding, resulting in the development of aquatic vegetation; these areas are located in the mountain regions of the country above 1,500 meters MSL.

411 Permanent wetlands
Areas deprived of trees where a natural hydrophytic vegetation grows.

412 Temporary wetlands
Areas temporarily flooded with appropriate vegetation.

42 Lowland vegetated wetlands
Areas of water caused by flooding in hydrologic systems; sites of changing water levels due to the rivers' hydrologic regimes; these areas are located in the eastern plains of the country and are characterized by dense communities of hydrophytic vegetation species.

421 Permanent wetlands
Areas, with or without scanty trees and permanently flooded where floating herbaceous vegetation (curiche) develops.

422 Temporary wetlands
Areas temporarily flooded that may or may not have woody vegetation (banados).

43 Non-Vegetated Wetlands
Comprising areas of temporary flooding without vegetation, located in the mountains and lowland zones.

5 WATER

Natural or artificial bodies of water with irregular forms; in this category are included large lakes, small lakes and ponds, rivers, and reservoirs.

Water areas with vegetation are included under the wetlands category.

51 Lakes
Natural volumes of permanent water, with large dimensions, that receive water from affluent drainage systems, including Lakes Titicaca, Uru Uru, and Poope.

52 Small lakes (including ponds)
Natural deposits of water without any affluent and with smaller dimensions than a lake.

521 Permanent lakes
522 Temporary lakes

53 Rivers
Water courses that may be continuous or intermitent.

531 Permanent rivers
532 Temporary rivers

54 Reservoirs
Artificial water empoundments of planned and defined dimensions and capacities.

6 BARREN LANDS

Lands not capable for agriculture or very limited in their use, sometimes covered with small native species of vegetation; these areas, for various environmental or cultural reasons, are poor, unproductive lands.

61 Salt Flats (salar)
Extensive and deserted areas covered with natural salt

62 Playas and Dunes
Playas are shallow basins, without surface drainage, in arid areas that occasionally may be transformed into a temporary lake. Dunes are accumulations of sand with regular forms molded by wind.

63 Exposed Rock
Areas with a predominance of gauging rocks, steep talus slopes, volcanic material, or other rock zones without vegetation.

64 Surface mines and quarries
Open mine sites resulting form the surface extraction of rocks, gravel, and/or minerals, and slag piles and other features associated with surface and surface mining activities.

65 Saline lands
Improductive areas caused by the formation of accumulations of salt minerals.

66 Badlands
Areas where the surface has a strongly dissected relief, preferentially developed in arid conditions, characterized by the presence of pinnacles and profound gullies.

67 Other
Other undifferentiated zones of barren lands.

7 PERMANENT SNOW AND ICE

Natural permanent accumulations of snow in the high mountains including those areas that for reasons of temperature and pressure may be transformed into permanent ice.

71 Fields with permanent snow
72 Glaciers
Masses of ice located in high mountains that slowly slip by gravity action.

8 TUNDRA

Periglacial areas, with soil that may be frozen most of the year; with vegetation predominantly of grassy species, commonly in the form of "bunch grass" or cushioned. The flora has a limited number of species with small development and low density.

81 Wet Tundra
Tundra located in areas with saturated soils, generally resulting from inadequate drainage.

82 Dry Tundra
Tundra areas in arid environments.

9 URBAN AREAS

Places of human habitation that constitute a nucleus of population with the requirements for human life in all of their manifestations. (Urban areas have priority for classification when they coincide with two or more categories.) Included are (1) cities, (2) towns, and (3) areas of transportation and communication facilities.

91 Cities
Large areas used for the habitation and functional activities of a large and concentrated human population. Cities contain a variety of sub-areas, providing housing and basic service and employment activities. Their location may be based directly by images or with supplementary information.

92 Towns and Villages (Pueblos)
A group of inhabitants in a place or region that has only limited basic services and employment activities. Their location may be based directly by images or with supplementary information.

93 Transporation and Communication
Facilities and features, characterized by linear landscape expressions, that provide for the movement of people, information, goods, etc.

931 Airports and landing fields
932 Railroads and roads
933 Others, pipelines, power lines, etc.

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APPLICATION OF LANDSAT AND SKYLAB DATA FOR LAND USE MAPPING IN ITALY L-25

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ABSTRACT

Utilizing LANDSAT and Skylab multispectral imagery of 1972 and 1973, a land use map of the mountainous regions of Italy was evaluated at a scale of 1:250 000. Seven level I categories were identified by conventional methods of photointerpretation. Images of multispectral scanner (MSS) bands 5 and 7, or equivalents were mainly used. If the quality of the data is good and if the interpreter has a general knowledge of the country, categories of levels II to IV can be mapped.

Areas of less than 200 by 200 m could be classified. It is possible to establish standard procedures for interpretation of multispectral satellite imagery. In this manner, land use maps can be produced for central and southern Europe. The results proved that the existing land use maps could be updated and optimized.

The complexity of European land use patterns, the intensive morphology of young mountain ranges, and time-cost calculations are the reasons that the applied conventional techniques are, for the near future, superior to automatic evaluation.

INTRODUCTION

For many earth scientific activities, land use maps form the basis for further planning and inventory preparation. Very often, the existing land use maps are many years old and do not correspond any longer to the existing situation.

Task

For several purposes, the Italian authorities plan a revised geoscientific "atlas" of the mountainous regions of Italy (Fig. 1). The land use map at the scale of 1:500 000 is part of this project and was carried out by order of the GEOTECNECO S.p.A. at S. Lorenzo in Campo (Pesaro, Italy). In collaboration with the geoscientists of this institute, the map was evaluated from multispectral satellite imagery.

The following seven level I categories had to be mapped:

1. Barren land (rocks, gravel)
2. Permanent snow cover, glaciers
3. Urban areas (including industrial areas and larger transportation patterns - streets)
4. Pastureland (areas covered by grass)
5. Agricultural areas (including plantations)
6. Forested areas
7. Water bodies, rivers, and lakes

For the identification of the land use units, conventional methods of photointerpretation were applied. In addition to this task, the possibilities were examined to which degree LANDSAT and Skylab imagery can be classified by the applied techniques.

Data Source

LANDSAT-1 MSS images taken during 1972 and 1973 were used as the data source. The 9-inch negatives (scale 1:1 000 000) were photographically enlarged to a scale of 1:250 000.. For most of the areas, the information loss acquired through repeated photographic processing of the images did not interfere with the detection of level I categories. For some key areas, a direct production of images from tape was carried out by PRAKLA Company. These images, showing maximum information of the MSS data, were generated on a scale of 1:200 000.

Furthermore, for some middle Italian and Sicilian areas, Skylab photographic data were produced in panchromatic and false color. By this means, a total cloud-free coverage of the areas of interest was obtained.

EVALUATION TECHNIQUES

Background Information

The basis of any photointerpretation is not only the experience of the interpreter but also detailed background information. The background information for our project consisted of

1. Existing land use maps at a scale of 1:200 000, produced 20 to 40 years before
2. Existing field data obtained through geological field investigations of the last 10 years
3. Detailed vegetation profiles

Information gained through field work proved to be the most accurate information and could be utilized with high confidence.

Interpretation Key

LANDSAT-1 multispectral scanner data.- For conventional photointerpretation, there are no significant differences of information between MSS bands 4 and 5 and between MSS bands 6 and 7. On the other hand, MSS bands 5 and 7 show the best contrasts of gray tones in vegetated and nonvegetated areas. Therefore, images of these two bands were chosen for the land use mapping.

From an earth scientific point of view, the utilization of data representing different vegetation cycles would be the best. This requirement could not be fulfilled over all areas because of the lack of continuous data. It turned out that, for the production of a preliminary base map, channel 5 was optimally suited. Band 7 was used to obtain additional information for discriminating various types of surface features. So, for example, the use of band 7 allows the separation of coniferous forest from deciduous forest and the clear identification of barren land. For the level I classification, the sensitivity of band 7 to soil moisture has been somewhat disadvantageous.

The diagrams of Figure 2 represent a qualitative comparison of gray tone classes obtained from bands 7 and 5. In the coordinate system, the land use categories were plotted as a function of their gray tone in both channels. It is evident that such schematic representations give only a very rough idea of the principles of evaluation. Of course, such diagrams do not reflect the experience of the interpreter, his ability to differentiate subtle gray tones, and his analytic ability to recognize the same category under different environmental conditions.

Furthermore, both diagrams do not express important criteria such as texture and morphology and also the synoptic knowledge of the geological conditions. An interpretative decision can be made by a combined analysis of all criteria, as shown for grass in Figure 3.

Skylab data (color and false color images).- Color photographs of Skylab (for example, 190 a, taken in September 1973) were projected on a scale of 1:250 000. Because of the outstanding color quality of these images, the following surface features could be clearly identified: forested areas, agriculturally used areas, grassland, and barren land. False color composites of Skylab data and also of LANDSAT-1 MSS data served as basic information for differentiating areas with grassland from agricultural land. The determination of borders between those two features has been very difficult in black and white images taken during late autumn, summer, or winter. During these seasons, the fields are not planted or are already harvested. In relatively dry areas, grassland and agricultural areas appear in almost unidentifiable gray tones when the field patterns are far below the resolution capabilities of the sensor system. The only reliable criterion for differentiation is a distinct red color represented in false color images.

Gray Tone and Color Tone

With respect to the physical properties, various surface features reflect incoming radiation at different intensity levels. The reflection intensity is translated on photographic data into a gray or colored tone. Therefore, the photographic density is one of the most important interpretative criteria. In addition, the density is very sensitive to uncontrollable factors caused by natural phenomena or by photographic processing techniques.

Impact of natural phenomena on photographic density.- In general, pictorial representations of the earth's surface are a combination of all possible factors expressed by the image density. Problems arise concerning the identification of surface features, regarded to be homogeneous from any earth scientific point of view. This is because such a homogeneity does not necessarily correspond to a homogeneous distribution of gray tones.

Therefore, in order to decide whether to deal with category a or b, further decisionmaking criteria have to be introduced. So, for example, a well-cultivated, fertilized, medium humid meadow may have a darker gray tone than an uncultivated grassland under the same environmental conditions. Grassland in an Alpine valley, for example, has a different gray value from grassland in a southern Italian Apennine valley. Grass growing on clay has a different dark gray tone than grass on limestone. The gray tone, the intensity of reflections, is mainly dependent on natural factors such as soil moisture, soil type, climatic zone, and local climate. Figure 4 represents some of the basic relationships between environmental parameters and gray values.

Another important factor, not taken into account, is the exposure of the surface to an illumination source - the sun. In areas with great relief, the identification of surface features is extremely difficult, not only because of the shadows themselves but also because of the change of the relative sun angle.

Another important factor is the changing state of vegetation during the year, that is, the change of reflectance depending on the seasons. Therefore, multitime imagery allows better identification and further differentiation of land use categories.

Impact of technical factors on photographic density.- The main technical factors influencing the density of images are related to the image generation itself. Concerning the generation of images from a digital tape, restrictions result from the dynamic range of the output device. The equipment used for data generation has an overall dynamic range of 16 gray levels. In comparison with the theoretical performance of the MSS scanner, with a dynamic range of 128 (MSS 5) and 64 (MSS 7) gray levels, the applied generated images represent reduced information. To minimize this effect, the available interval of 16 gray tones was adapted to the actual sensitivity range of the scenes. To obtain maximum gray resolution for the areas of interest, the adaption was carried out on scenes that did not show maximum reflective contrasts, such as snow and water, in infrared images.

A second important parameter that influences the quality of the film material is the degradation effect resulting from photolab processings such as enlarging, etc. During these processes, the gray tones are influenced by the various film emulsions, by various exposure times, and by the state of the chemical ingredients.

Another degradation effect that occurs mainly in channel 7 is caused by the high contrast between water and land masses. The extreme dark water areas interfere in such a way that the coastal areas always appear in darker gray tones.

The above-mentioned photographic factors may especially degrade the possibilities and the accuracy of conventional photointerpretation techniques. In other words, the interpreter has to revise his interpretation results not only from image to image but also within the evaluation of one scene.

POSSIBILITIES AND LIMITATIONS OF THE CONVENTIONAL CLASSIFICATION

The possibilities of identifying surface features are extremely dependent on the resolution capabilities of the sensor and on the target size. Figure 5 demonstrates to what degree, under optimum conditions, the differentiation of trees can be made.

With regard to trees or tree-cones, two points have to be considered. With respect to the resolving power of the multispectral scanner, larger areas with a dense tree population can be identified as uniform reflecting areas. It is understood that, with a dense population of trees, there is no interfering reflection from the ground. Furthermore, because of the poor resolution of the satellite data, the differentiation between bushes and forests cannot be made.

Conventional definition based on the percentage of trees within a certain area can not be made. To a certain degree, gray tone and background information

enable the interpreter to map areas with different densities of wood. The geometric resolution of LANDSAT-1 images, however, does not permit the interpreter to map woods by quantitative measurements of percentage of trees per area. Therefore, areas with, for example, 10 percent trees, which are conventionally defined as wood, do not appear on the evaluated land use map.

Further difficulties arise when comparing forests and plantations. Densely planted hazel or citrus plantations and vineyards have the same reflection characteristics as deciduous forest, at least for the eye. Basic local knowledge and experience in examining textural information may sometimes help to overcome the above-mentioned difficulties. Plantations, for example, are very often characterized by geometric borders; in contrast, vineyards often show a kind of chaotic texture.

Cultivations with clearly separated rows of plants such as olive yards are characterized by a uniform medium gray value. These gray values are originated by intensities reflected from the ground coverage and the foliage of the trees.

The following images demonstrate areas with plant units that have characteristic signatures. Figure 6 shows coniferous and deciduous forest of Pratomagno Mountains southeast of Florence; Figure 7, Mediterranean oaks in the Apennine west of Rieti; Figure 8, olive yards of the Tuscany; and Figure 9, an area with bush and grassland near Valle Taleggio (Bergamasc Alps). The last example (Figure 9) especially indicates the difficulties that result from the limits given by the geometric and spectral resolution of LANDSAT-1 images.

Areas with mixed reflections are very difficult to classify without knowledge of the local conditions. Normally in such cases, textures can not be detected and the surfaces appear rather uniform. The limitations of differentiating between various surface features become evident if we are looking at interface regions between meadows and areas with dried-out grass and barren rocks. Barren rocks are clearly detectable but a distinct tracing of the border between the grassland and areas without vegetation is impossible.

DISCUSSION OF THE RESULTS

The possibilities of conventional interpretation mentioned above are based on extreme situations. With respect to the seven level I categories, the results are good.

Mapping of Land Use Categories

The land use classification followed the USGS system established by Anderson, Hardy, and Roach (Ref. 1) for the interpretation of remote sensing data. For our special problems, there was introduced the level I category "grassland," which in the USGS system belongs to "agricultural land" if it is pasture and to "range land" if it is uncultivated.

Table I shows to what degree LANDSAT and Skylab images can be used for mapping land use categories of level I and II. The table is based on our experiences during this work and therefore is valuable for European mountainous regions.

Good satellite data and good background information enable the interpreter to subdivide the level I categories 2, 4, 5 and 6 in the level III and IV categories. Table II shows these subdivisions, which are not included in the USGS system. Many categories, however, are not sharply bordered because of a gradual change of gray tone, that is, a zone of mixed vegetation. Even if the categories can be identified, such cases produce great uncertainty and errors in bordering different land use categories, especially if the scale is large.

Cartographic Accuracy

Besides methodological problems and their solution, it is important to calculate the cartographic accuracy. At the scale of 1:1 000 000, no important differences in the geometric accuracy between LANDSAT-1 images and topographic maps are remarkable. During mapping, the enlargements (squares of 10 by 10 cm) were rectified by using exact topographic features identical in the images and in the topographic maps. Finally, the geometric accuracy was as good as required for maps at a scale of 1:250 000. Areas of 1 by 1 mm (i.e., 250 by 250 m) were mapped so that the geometric resolution of topographic maps also was obtained.

Comparison With Other Methods of Mapping

The quality of new methods is generally compared with the results of former "conventional" techniques. Existing land use maps could be modified and generally updated. Borders between categories could be drawn more objectively compared with conventional maps. For example, with respect to woods, the borders taken from satellite images were more accurate than those of existing land use maps. This can be explained by two reasons: (1) those areas which were mapped from aerial photographs lost their initial accuracy by the generalization necessary for a scale of 1:250 000, and (2) if the map is based on field work, the borders can only be drawn roughly. In both cases, the need for time and costs is much higher than for the interpretation of satellite imagery.

Comparison With Automatic Digital Classification

Because of the difficulties described in the above chapters and because of the digital original MSS data, the question must be asked whether an automatic digital classification would not be preferred to the conventional methods of photointerpretation. Only a time-cost calculation can answer this question.

At first, there are two important facts:

1. A European mountainous region of approximately 200 000 km^2 was mapped. This area would be covered by six LANDSAT frames.
2. Level I categories were mapped. They include many subcategories that had to be combined. The subcategories result from differences in vegetations and soils.

For comparison, the time needed for the conventional interpretation has to be taken in consideration.

2 months	mapping	five photogeologists
1 month	photographic laboratory work	one photographer
1 month	ground truth	two geologists

Because of the overlapping of processes, the entire map was done in 3.5 months.

Furthermore, at the recent state of automatic digital classification, there must be done some premises:

1. All necessary computer programs must be established; that is, programs for the statistics and programs for the correction of gray tones, which is very important especially in mountainous areas with an intensive relief and with a small-scale pattern of different soils.

2. The computer must be capable of combining the level I categories from the very large number of subcategories that are often very similar to one another.

Although automatic digital classification is already done for small European areas and also because of the intensive experiments on this field, it is obvious without an exact calculation:

1. The computer will probably classify much more quickly than an interpreter.

2. The classification pixel by pixel will be much more exact than a conventional interpretation.

3. The costs for computer time will be much higher than the costs for interpreters, materials and field work.

Furthermore, the high degree of resolution is not necessary because areas of 80 by 80 m can not be figured out at a scale of 1:250 000 or less.

Despite the possibilities offered by statistics and by computers, the automatic digital classification must solve the same problems as the conventional photointerpretation. A computer needs background information as well as the human interpreter. It is very difficult, however, to code all important background information in a way that a computer can work with them.

Summarizing, the discussion shows that for large mountainous areas with small-scale land use pattern and intensive morphology such as in Europe, the conventional photointerpretation for the moment is superior to automatic methods. For operational use, digital evaluation has to pass the experimental stage.

REFERENCE

J. R. Anderson, E. E. Hardy, and J. T. Roach: A Land-Use Classification System for Use With Remote Sensing Data. Geological Survey Circular, 671, 1-16, Washington, 1972.

TABLE I.- QUALITY OF LANDSAT-1 AND SKYLAB IMAGERY FOR

LAND USE MAPPING IF LEVEL I AND II CATEGORIES ARE WANTED

Level I	Level II	Multispectral Imagery[a]	
		LANDSAT	Skylab
1) Built-up Land		++ o	++
	Residential	+	+
	Commercial	+	+
	Industrial	+	+
	Communications	+	+
2) Agricultural Land		+++ o	+++
	Fields	+++ o CIR	+++ HP/A
	Plantations	++ o CIR	+++ HP/A
3) Grassland		+++ o CIR	+++ CN/CIR/A
	Pasture	+ o CIR	++ HP/CN/CIR/A
	Uncultivated	+ o CIR	++ HP/CN/CIR/A
4) Woods		+++ S	+++ S/A
	Deciduous	+++ S	+++ CIR
	Coniferous	+++ o	+++ CIR
5) Water		+++	+++
	Streams, Waterways	+++ (o)	+++
	Lakes	+++	+++
	Reservoirs	+++	+++
6) Barren land		+++	+++
	Beach	+++	+++
	Sand	+	+
	Rocks	+	+
7) Permanent snow/ glaciers		+++	+++

[a]Legend:

+++ Identification $\geq$ 90%

++ Identification $\leq$ 90%

\+ Identification only in special cases; ground truth knowledge

o sequential imagery

S Images taken in summer

A Images taken in autumn

HP High precision photograph

CN Natural colors

CIR False colors

TABLE II.- LEVEL III AND IV CATEGORIES WHICH CAN BE DISTINGUISHED ON LANDSAT-1 IMAGERY OF ITALY

Level 1	Level II	Level III	Level IV
2. Agricultural land	Acres	Grain	Wheat Rice
	Plantations	Truck crop Vineyards Orchards Olive yards Citrus Nut-plantations	
4. Woods	Deciduous	Deciduous Evergreen	Chestnuts Mediterranean Oak
		Deciduous	Macchia
	Coniferous	Spruce Pines, Stone pines Larches	
5. Water	Lakes	Natural Artificial	Shallow Deep
	Rivers Channels		Plus suspension
6. Barren land	Barren rock	Volcanic Sedimentary	 Limestone Sandstone Marles, shales

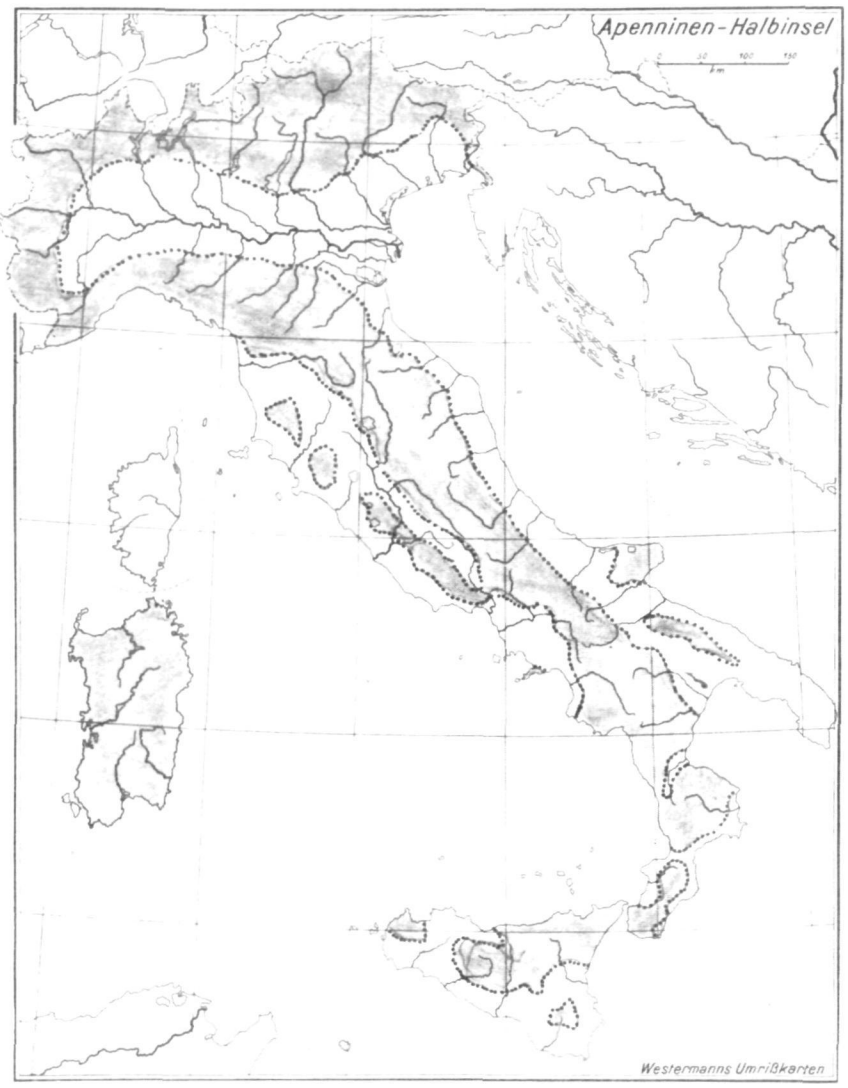


Figure 1. - The mountainous regions of Italy (gray = mapped area).

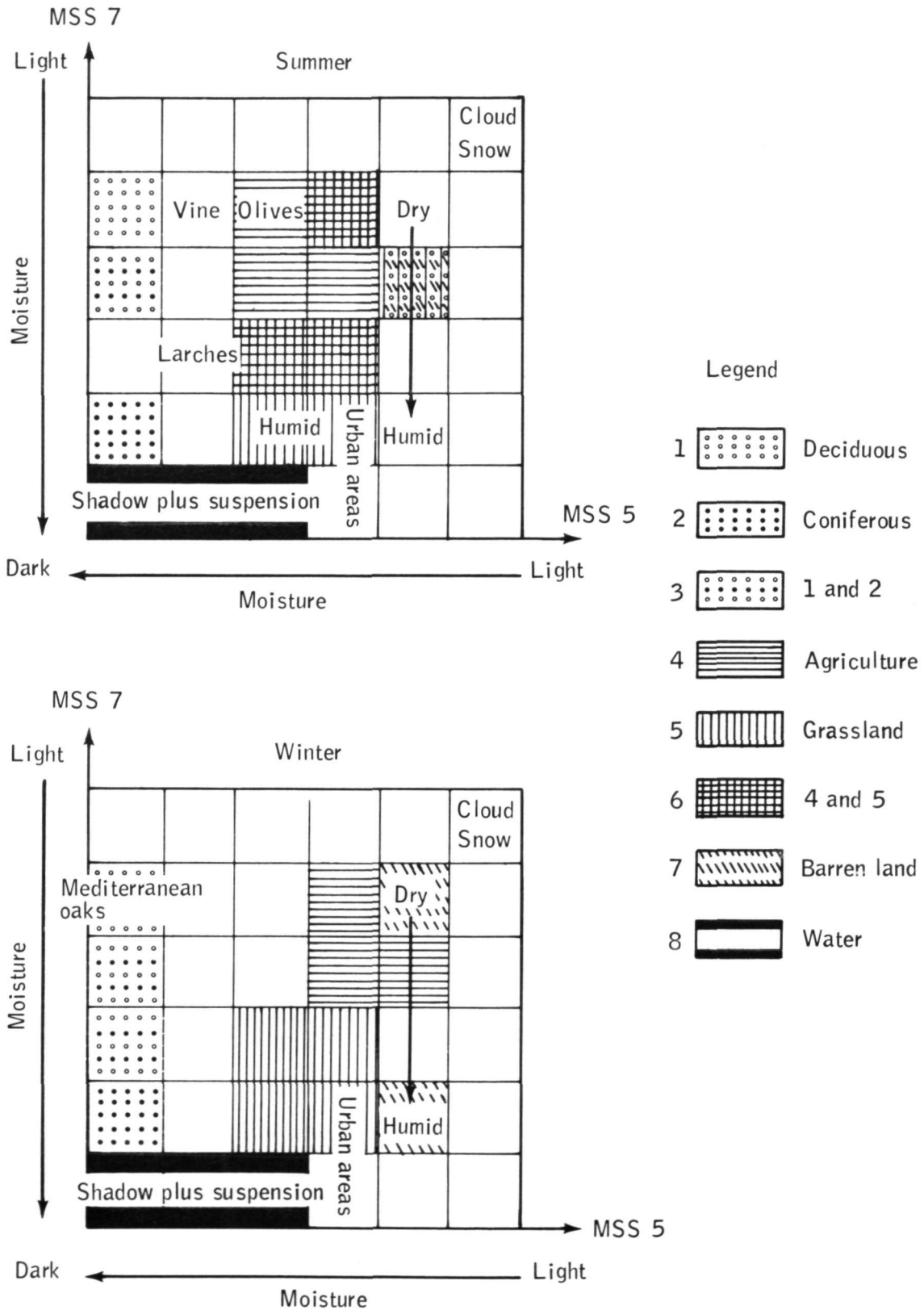


Figure 2. - Schematic position of land use categories in a coordinate system based on the gray tone in LANDSAT images of MSS 5 and 7.

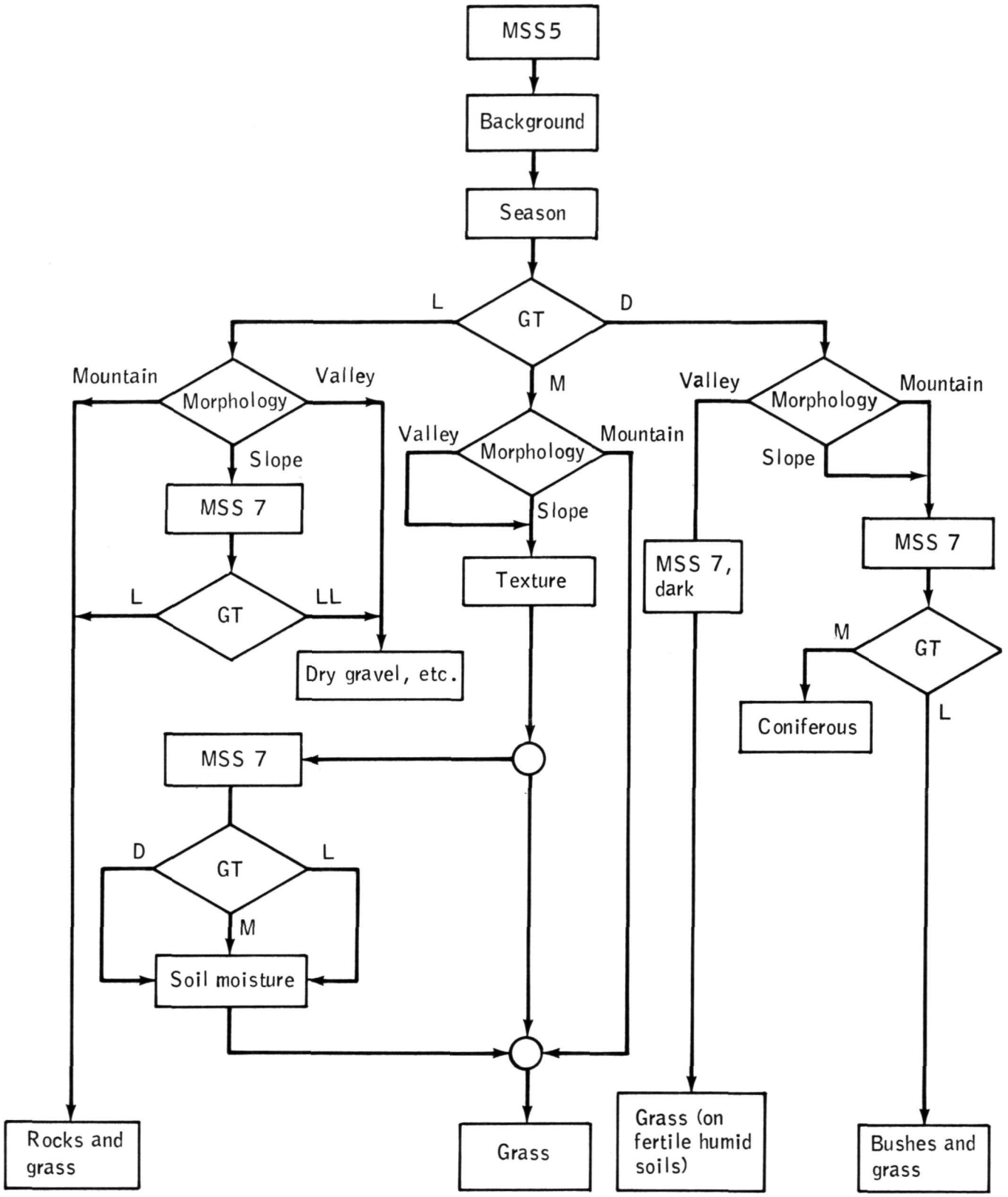


Figure 3. - Identification of grassland: schematic diagram for the interpretation of LANDSAT MSS data (GT = gray tone, L = light, LL = very light, M = medium, D = dark).

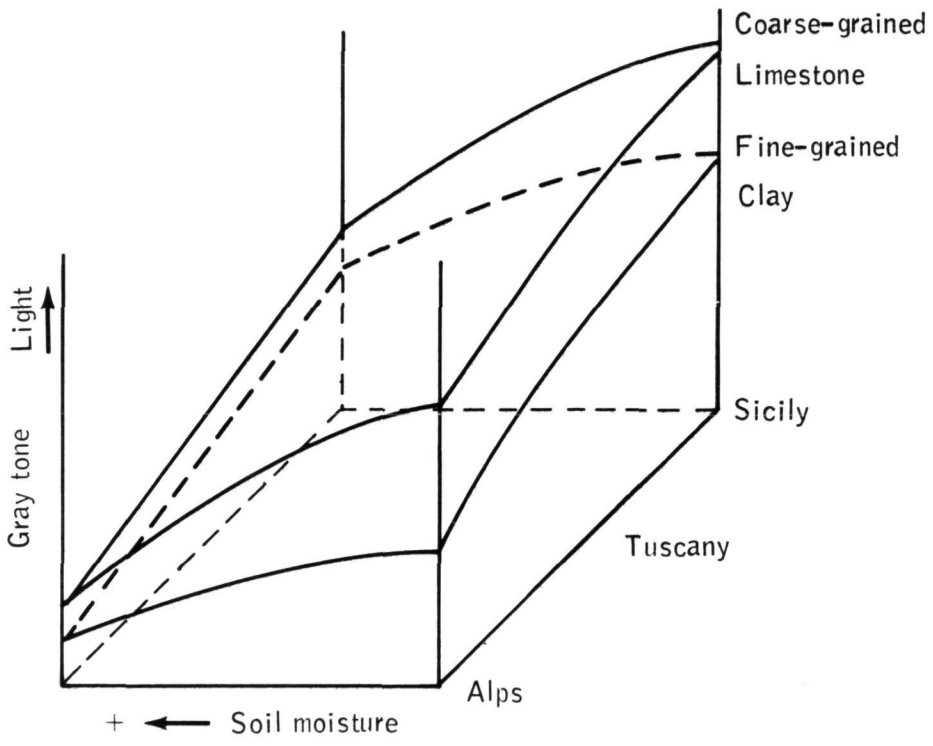


Figure 4. - Gray tone levels of grass; schematic representation for the factors of soil type, soil moisture, and climatic zone.

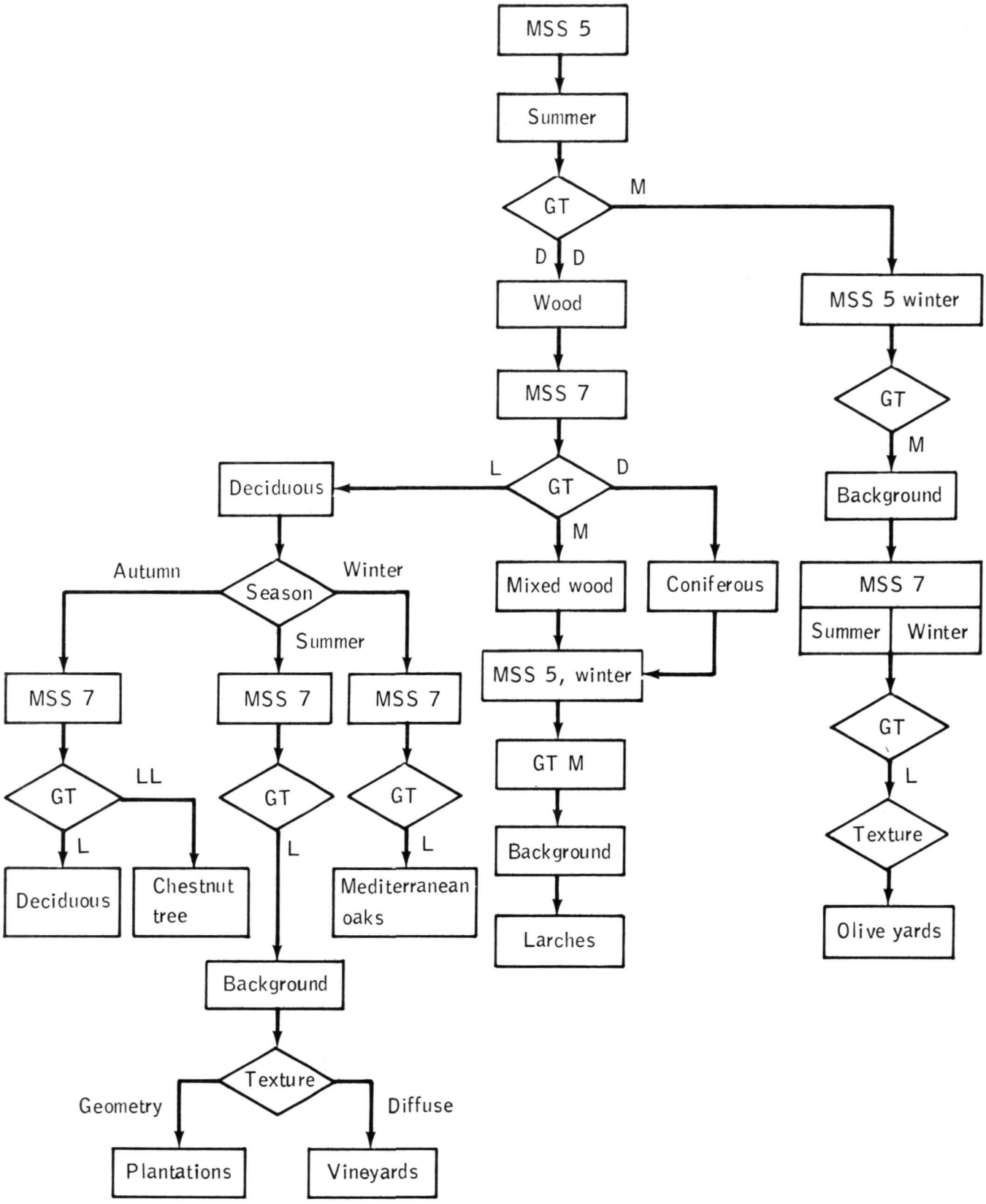
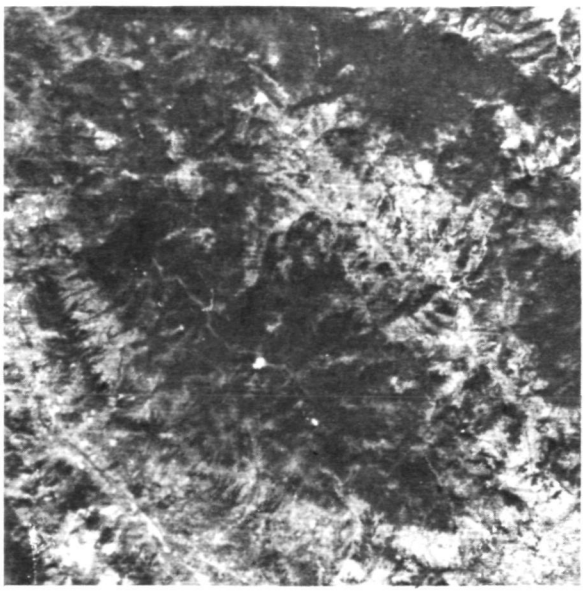
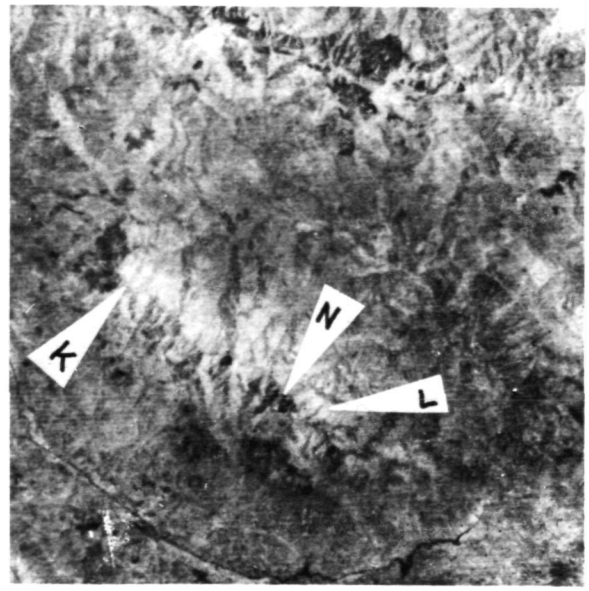


Figure 5. - Identification of wooded areas; schematic diagram for the interpretation of LANDSAT MSS data (GT = gray tone, L = light, LL = very light, M = medium, D = dark, DD = very dark).



(a)



(b)



(c)

Figure 6. - Pratomagno Mountains southeast of Florence.
(a) Detail of LANDSAT image of 12 Aug. 1972, MSS 5 (dark = woods).
(b) Detail of LANDSAT image of 12 Aug. 1972, MSS 7 (light = deciduous woods, L = general, K = chestnuts, N = coniferous).
(c) Ground truth photograph showing coniferous (dark) surrounded by deciduous.

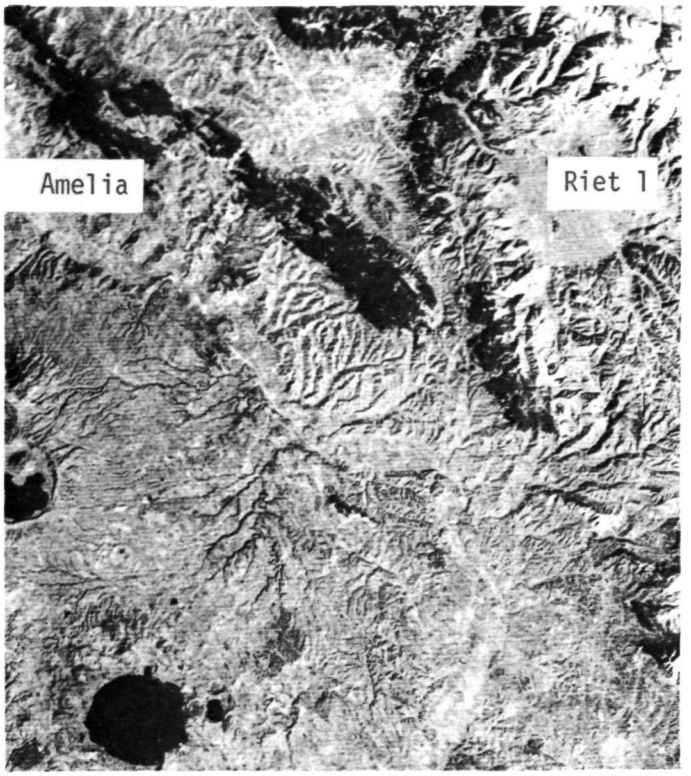


Figure 7(a). - Mountain ranges west of Rieti (detail from LANDSAT image of 6 Feb. 1973; MSS 5) (dark = evergreen, mediterranean oaks).



Figure 7(b). - Ground truth photograph taken in June 1973 near Amelia. The hill is covered by evergreen Mediterranean oaks.

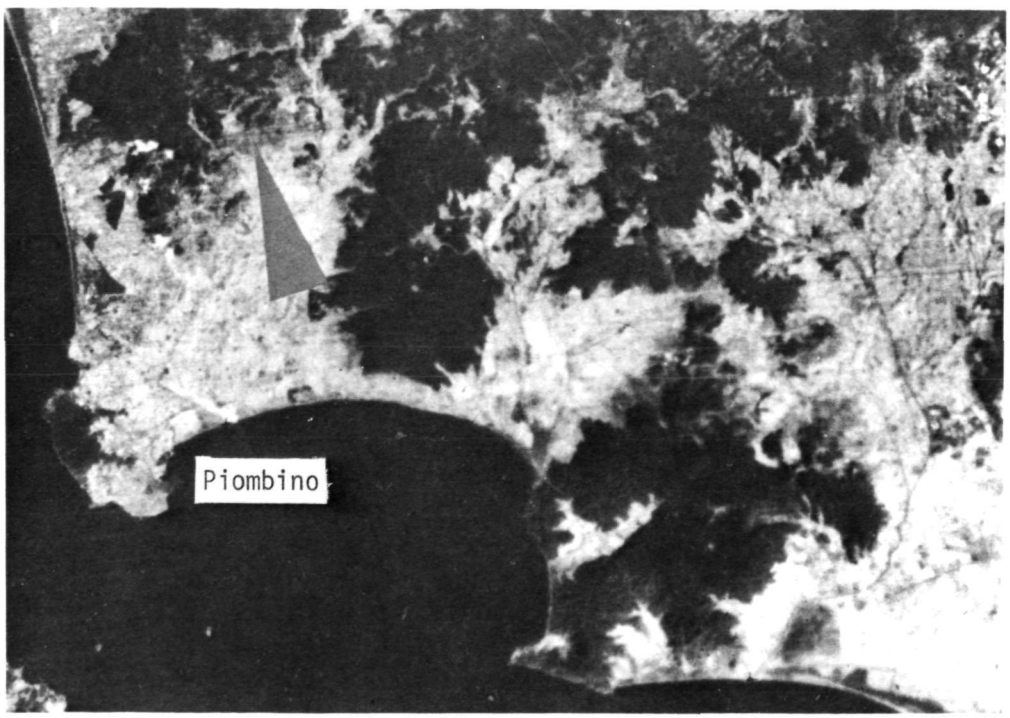
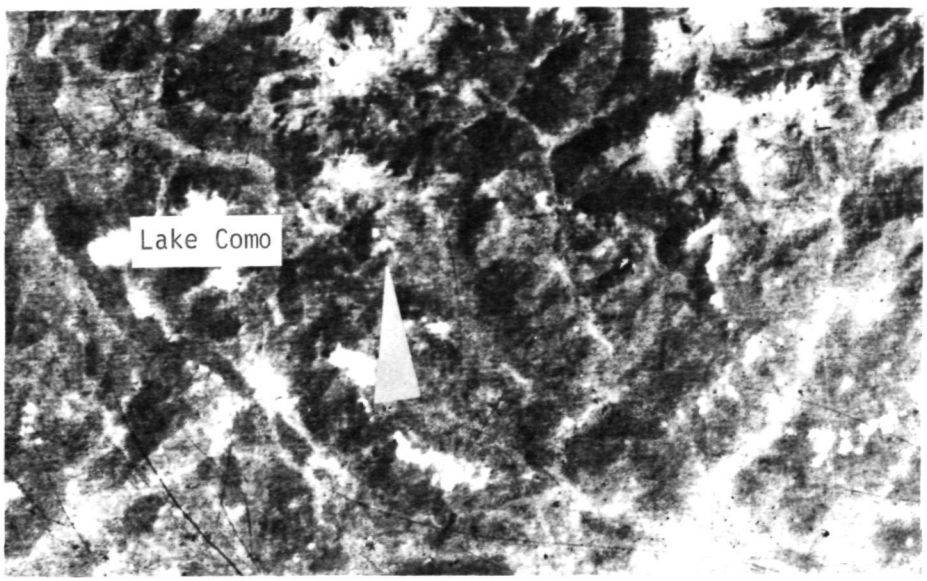


Figure 8. - Lower valley of the Cornia River, east of Piombino (detail from LANDSAT image of 12 Aug. 1972; MSS 5) (dark = woods, middle gray = olive yards (arrow)).



(a)



(b)

Figure 9. - Valle Taleggio (Bergamasc Alps, east of Lake Como). The detail from LANDSAT image of 7 Oct. 1972 (MSS 5; fig. 9(a)) does not show the distinct vegetation pattern as does the ground truth photograph (fig. 9(b)). The arrow in the LANDSAT image marks the moutain ridge shown in the photograph.

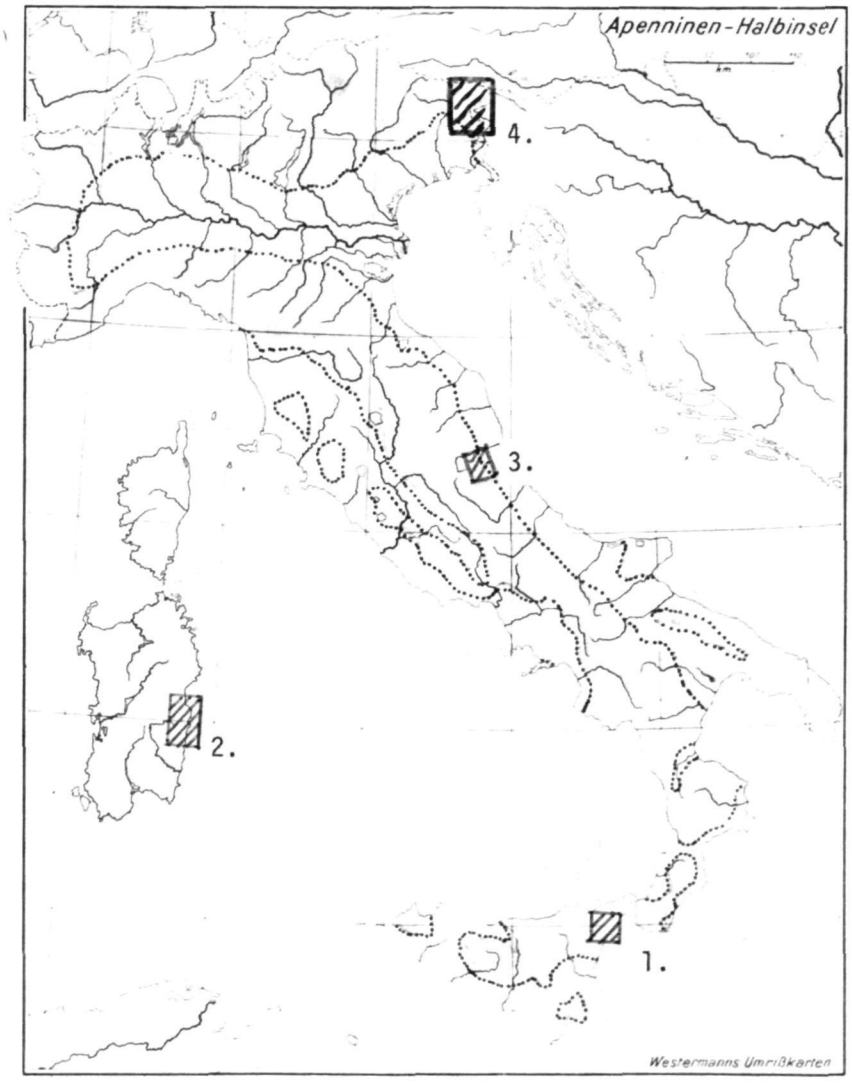


Figure 10. - The map of Italy showing the map sections:
(1) Mount Etna area (see fig. 11).
(2) Eastern Sardinia (see fig. 12).
(3) The Marchigiano Apennines west of Ascoli Piceno and Teramo (see fig. 13).
(4) The Alps north of Udine (see fig. 14).

A P P E N D I X

SOME MAP SECTIONS OF THE LAND USE MAP OF ITALY

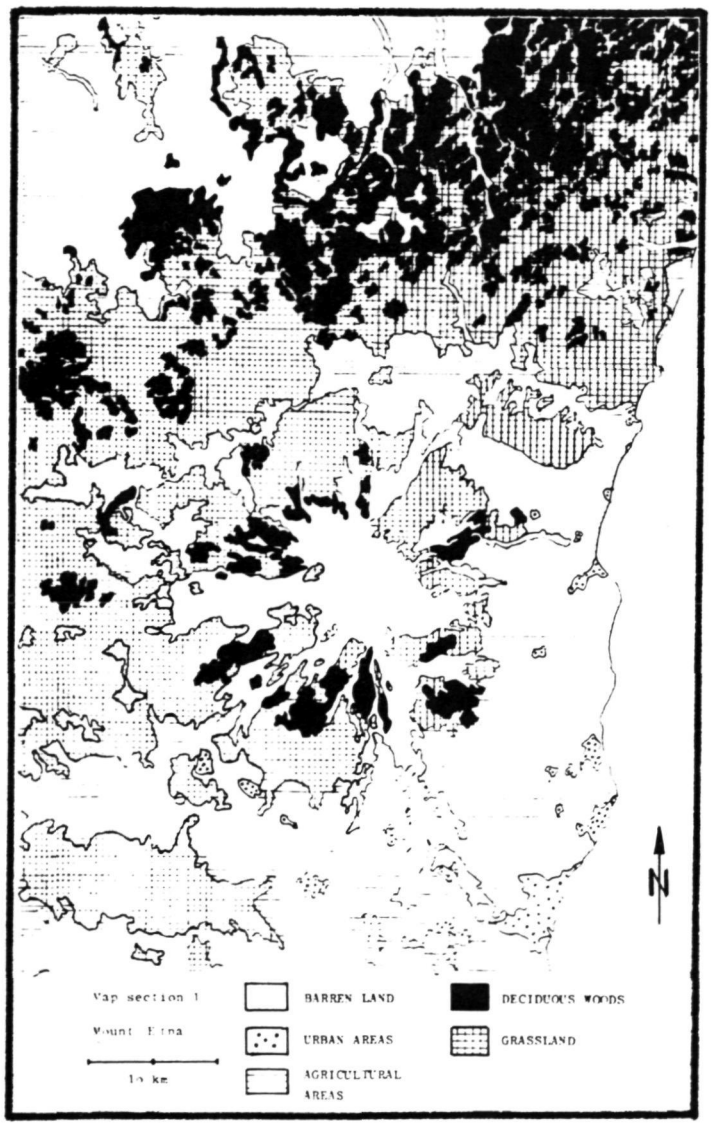


Figure 11. - Mount Etna area (Sicily); section of the land use map of Italy. Especially in the northern part, the plantations (agricultural land) and deciduous woods were separated by Skylab false color photographs.



Figure 12. - Eastern Sardinia; section of the land use map of Italy. The differentiation between grassland and more or less wooded grassland was very difficult. In some areas (northwestern part of the figure), it was possible to map only after the field check.



Figure 13. - Map section 3: The Marchigiano Apennines west of Ascoli Piceno and Teramo. (Legend - see figs. 11 and 12) This area was mapped from Skylab high-precision photographs in natural colors. These kinds of photographs offer best possibilities for the mapping of gradual vegetation changes (grass or woods/barren rocks).

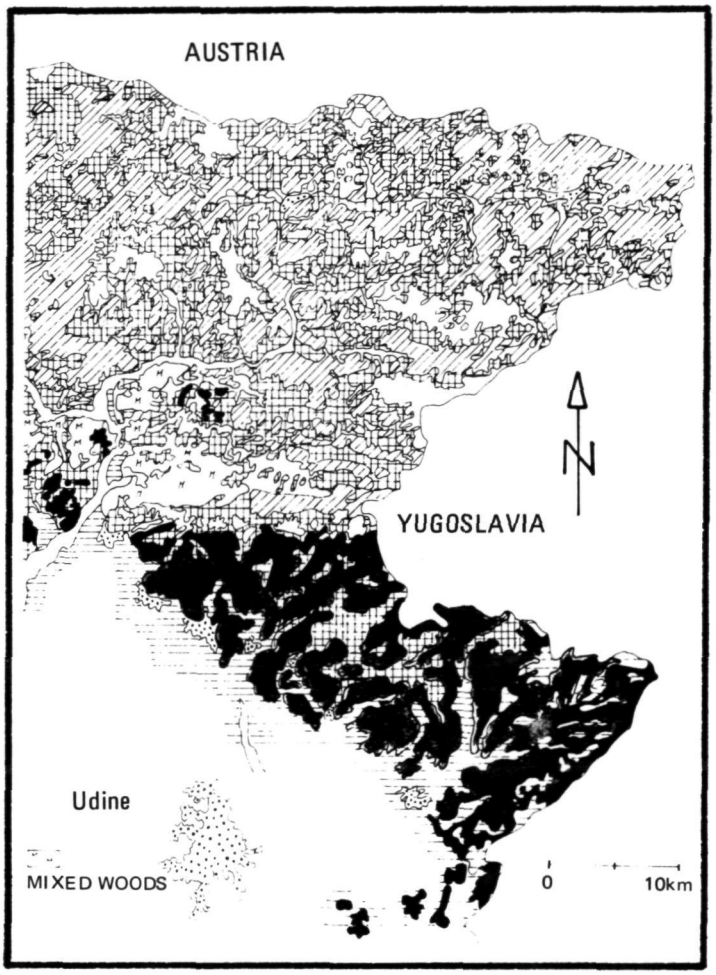


Figure 14. - The Alps north of Udine (legend - see figs. 11 and 12). In this area, it was possible to detect many urban areas. In the middle of the map section, the gray tone of the LANDSAT image indicated mixed woods.

THE SIGNIFICANCE OF THE SKYLAB ALTIMETER EXPERIMENT RESULTS AND POTENTIAL APPLICATIONS

M-1

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ABSTRACT

The Skylab Altimeter Experiment has proven the capability of the altimeter for measurement of sea surface topography. The geometric determination of the geoid/mean sea level from satellite altimetry is a new approach having significant applications in many disciplines including geodesy and oceanography. A Generalized Least Squares Collocation Technique was developed for determination of the geoid from altimetry data. The technique solves for the altimetry geoid and determines one bias term for the combined effect of sea state, orbit, tides, geoid and instrument error using sparse ground truth data. The influence of errors in orbit and a priori geoid values are discussed. Although the Skylab altimeter instrument accuracy is about ± 1 m, significant results have been obtained in identification of large geoidal features such as over the Puerto Rico trench. Comparison of the results of several passes shows that good agreement exists between the general slopes of the altimeter geoid and the ground truth, and that the altimeter appears to be capable of providing more details than are now available with best known geoids. The altimetry geoidal profiles show excellent correlations with bathymetry and gravity. Potential applications of altimetry results to geodesy, oceanography, and geophysics are discussed.

INTRODUCTION

The Skylab S-193 altimeter experiment was the first of a series of altimeter experiments recommended by the "Williamstown Study" [1], and the NASA "Earth and Ocean Physics Applications Program" (EOPAP)[2]. The primary objective of the Skylab altimeter experiment was to determine the engineering feasibility of the altimeter instrument and demonstrate its capability for measurement of sea surface topography.

Three manned Skylab missions--SL/2, SL/3, and SL/4--provided data from the S-193 system. Geodetic analysis of Skylab S-193 altimeter data from mission SL/2 EREP pass #4, 6, 7, and 9 is the subject of this paper. The overall objective of the Battelle investigation is to demonstrate the feasibility of and necessary conditions in using the altimeter data for the determination of the marine geoid (i.e., the geoid in ocean areas). The geoid is the equipotential surface that would coincide with "undisturbed" mean sea level of the earth's gravity field. "Undisturbed" is the condition that would exist if the oceans were acted on by the earth's force of gravity only and by no other forces such as those due to ocean currents, winds, tides, etc. Thus, determination of the geoid/mean sea level is basic to the understanding of the oceans and associated dynamic phenomena such as currents, tides, circulation patterns and, hence, air-sea interactions. There exist many geoids which have been computed by various methods. Most of these lack the accuracy and quality required for many scientific and practical applications.[3]

Present methods of determining the geoid depend on the knowledge or measurement of the detailed gravity field all over the earth and the use of satellite perturbations to describe the general field. Measurement of the gravity field all over the earth requires the use of land-based, shipborne, airborne and ocean-bottom gravity instruments, a process which will take decades to achieve an accuracy of the order of 1-3 meters. Present knowledge of the geoid on a world-wide basis is probably not better than 5-30 m.

The use of altimetry for determining the geoid is, perhaps, most significant because of its fundamental applications to geodesy, oceanography, geology, geophysics, navigation, national defense, environment, resource development and several other applications. Satellite altimetry offers the most expedient and accurate method for determining the geoid independent of gravity measurements. An accuracy of ± 10 cm for determining the marine geoid from satellite altimetry is the goal of the NASA's EOPAP.[1] The results obtained from the Skylab S-193 altimeter experiment proved that the concept is feasible. The extent of applications of altimetry data to various disciplines and uses will depend on the degree of accuracy achieved and correlation that can be made between these data and the parameters involved in the application areas.

CONCEPT OF GEOID DETERMINATION FROM SATELLITE ALTIMETRY AND REQUIREMENTS

Figure 1 shows schematic geocentric relations of the various surfaces associated with satellite altimetry. TM is the raw altimeter range which has to be corrected for laboratory instrumental calibration, electromagnetic effects, sea state, and periodic sea surface influences to give TS. S represents the non-periodic "sea level". CT and CE, the geocentric radii of the altimeter and E, its subsatellite point on the reference ellipsoid, are computed from satellite tracking information. EG is the absolute geoidal undulation to be computed from this investigation, while SG is the quasi-stationary departure of the mean instantaneous sea surface from the geoid - the "undisturbed" mean sea level. It can be seen from Figure 1 that the required geoidal undulations are given by

$$EG = ET - TM - MS - SG \qquad (1)$$

where, MS represents the sum of the calibration constants and the orbit uncertainties, if any. SG represents the deviation of the surface to which the measurement is made from the geoid. Since we do not have any information on SG which is not considered to vary significantly over the length of profiles corresponding to different submodes of observations, the sum (MS + SG) is considered as the calibration constant.

The basic requirements for determining the geoid from satellite altimetry are:

1. accurate orbit determination;
2. precise altimeter instrumentation;
3. ground truth verification data;
4. methods of interpolating and extrapolating altimetry into unsurveyed areas; and
5. separation of the geoid from sea surface topographic effects.

The geoid to be determined must be in absolute position or geocentric (i.e., centered at the earth's center of mass) and have correct scale, shape and orientation in order to meet the goals of geodesy and also make contributions to the solution of problems in earth gravity modeling, geophysics, oceanography, etc. Correctness of shape depends on the precision of the altimeter and, in theory, absolute centering and orientation are dependent on the satellite orbit ephemeris. The correctness of geoid scale requires that the orbit ephemeris and the altimeter either have no biases or systematic errors, or that such biases and systematic errors must be known to an accuracy better than the error tolerance of the geoid to be computed. Currently and for some time to come, these two scalar conditions cannot be met because of unknown systematic errors or biases in tracking station geocentric coordinates, the earth's gravity model, the tracking systems and the altimeter itself. There is, therefore, a need for other sources of scale and orientation control, which can be satisfied by the use of good ground truth geoid data. Poor ground truth data will only result in a

coarse scale. Fine scale, if necessary, has to be introduced through some form of marine geodetic control. Since there is no established marine geodetic control available at present, the geoid computed in this paper will only have a coarse scale provided by the a priori geoid height input.

APPROACH AND MATHEMATICAL MODEL

The approach to this analysis consisted of two basic steps. The first step was to filter the noisy altimetry data using the Generalized Least Squares Collocation technique. In the second step, the filtered altimetry data were compared with the a priori ground truth geoid in order to determine the calibration constants and the altimetry geoid profile. The basic purpose of this comparison was to have the altimetry geoid data on the same scale as that of the a priori geoid. The details of the procedure used in this analysis is discussed in Mourad, et al.[4] The general mathematical model used in this analysis consists of the linear relationship between the residual altitude from the altimetry data, the a priori geoid, and the calibration constants. For the purpose of this investigation, only one constant term representing the cumulative effect of all the possible systematic errors associated with the residual altitude, is used as a calibration constant.

The basic condition equation is

$$D_i - R_i = N_i + \Delta C + n_i \qquad (2)$$

where, R_i is the measured altimeter range, which is intrinsically related to

1. the geocentric coordinates, X_{si}, Y_{si}, Z_{si}, of the satellite at the instant of measurement;
2. the geoid undulation, N_i, referred to a given reference ellipsoid at the subsatellite point; and
3. the algebraic sum of the biases in all the measurement systems involved.

Except for the noise term (n), equation (2) is the result of rearrangement of equation (1) with ΔC, which is the total bias term involved in the measurement, representing the sum (MS + SG) and with

$$D_i = F(X_{si}, Y_{si}, Z_{si}, a, f) \qquad (3)$$

representing the height of the satellite above the reference ellipsoid given as a function of the geocentric coordinates of the satellite at the instant of observation and with a and f being the parameters (semi-major axis and flattening) defining the size and shape, respectively, of the assumed reference ellipsoid. It is important, however, that both D_i and N_i [Equation (2)] refer to the same reference ellipsoid. If they do not, they must be made compatible by effecting the appropriate corrections as and when they are necessary.

The general theory of Least Squares Collocation is presented in Moritz,[5] and the details of its application to filtering the altimetry data are described in Mourad, et al[4]. The filtered altimetry observations, s, are given by:

$$s = N + \Delta C = C_{ss} \bar{C}^{-1} (D - R) \qquad (4)$$

where, C_{ss} is the auto-covariance matrix for the geoid undulations corresponding to the altimetry observations,

$$\bar{C} = C_{ss} + C_{nn} \tag{5}$$

with C_{nn} being the error covariance matrix for the altimetry observations. Equation (5) implies that the geoid undulations and the altimetry observations are stochastically independent. The subscript $_1$ is left out in equation (4) to indicate that the equation is in matrix notation and represents a set of several equations corresponding to equation (2).

The elements of the covariance matrix C_{ss} are evaluated from a table of numerical covariance function, from Tscherning and Rapp [6], using linear interpolation method. The covariance between any pair of undulations is given as a function of the spherical distance between these undulations.

The output resulting from filtering the altimetry data is a set of filtered residual altitudes given by

$$s = N + \Delta C \tag{6}$$

If s and N are accurate, ΔC can be estimated by evaluating equation (6) at any one point. However, in order to minimize the uncertainties, if any, in the ground truth geoid, this equation is evaluated at several points along the profile using Least Squares Adjustment principles. s is considered observable and ΔC and N are parameters to be estimated. In matrix notation, the observation equation corresponding to equation (6) would be

$$V + AV_x + W = 0 \tag{7}$$

where, V is the vector of residuals on -s and V_x is that on ΔC and N. A is the design matrix and W is the misclosure vector obtained by evaluating $(N + \Delta C - s)$ with the 'observed values' for s and the a priori ground truth data for N. The a priori values for ΔC can be assumed to be zero. If the weight matrices of the observables and the parameters are P and P_x respectively, the matrix solution for the residuals for the parameters is given by

$$V_x = -(A^T PA + P_x)^{-1} A^T PW \tag{8}$$

Then, the altimetry geoid undulations, N, are given by

$$N = s - \Delta C \tag{9}$$

If stochastic independence is assumed among observables and among parameters, P and P_x will be diagonal matrices. Those elements of P corresponding to ΔC can be assumed to be zero.

Preliminary examination of the Skylab altimetry data revealed that every time the submode of the altimeter changed, there appeared to be a change in bias in the measured altitude. Consequently, separate bias terms were assumed for data from the segment of the profile observed in a single mode-submode combination. These bias terms can be recovered simultaneously by suitably modifying the design matrix.[4]

Consideration of separate bias terms for different segments may result in a discontinuity from one segment to the other. This can be rectified by constraining the closest ends of the two adjacent segments to have the same value of undulation even though these ends do not correspond to the same point. This is a reasonable assumption considering the accuracy of the Skylab altimetry system combined with the small variation in undulations over short distances of about 8-15 km. In this analysis, these constraints are effected through sequential solution, which means that the effect of the constraints on the parameters is evaluated and added to the solution obtained from equation (8). The reason for this approach is the convenience and efficiency resulting from the special structures of the matrices involved.

RESULTS AND CONCLUSIONS

The major results obtained can be divided broadly into two groups. One group is concerned with the effects of errors inherent in the various input data such as the orbit ephemeris, a priori geoid, etc. The other consists of the results of the actual analysis of the data from the Skylab EREP passes #4, #6, #7, and #9.

Results of Preliminary Data Analysis

The results from the first group have been obtained from the analysis of some preliminary data from EREP pass #9 mode 5. The use of such preliminary data was necessary in the absence of actual data which were not available at the time of the error analysis. Details of the preliminary analysis are described in Fubara and Mourad.[7] Figures 2 and 3 show only two important results. Figure 2 shows the influence of a priori geoid height on the geoid scale. It shows that such a priori geoid input and errors in them affect only the linear scale and not the shape of the geoid. This is due to the fact that any inherent error is modeled by a constant bias. The a priori geoid input was taken from Vincent and Marsh geoid[8] (GG-73 in Figure 3). AA is the resultant altimetry geoidal profile based on GG-73 as a priori input. Two different sets of errors were introduced into GG-73 to produce A-I and B-I. This resulted in altimetry profiles A-O and B-O. It is obvious that AA (control experiment) is shape-wise identical to A-O and B-O. However, the scale of the calibration constant has changed considerably in the same altimetry profiles. Figure 3 shows that the scale and orientation of the computed altimetry geoid is highly dependent on the orbital data used. In this analysis, two sets of orbital data (computed independently using different methods) were used. These resulted in the altimetry geoidal profiles AA and BB. The scale discrepancy was removed through the calibration constant used. However, the difference in orientations remained. The close agreement between AA and GG-73 may be due to the use of basically the same gravity model and coordinate frame in their computations.

To summarize, results demonstrated that:

1. the precision of the altimeter ranges affect the shape of the geoid;
2. the orbit uncertainties affect both the scale and orientation; and
3. available a priori ground truth geoids can give only a coarse scale to the altimetry geoid.

Thus, to get an absolute geoid correct in scale and orientation, marine geodetic controls to offset the systematic errors in the orbit and altimeter data appear to be required.

Results of Final Data Analysis

The analysis of the altimetry data was made only for EREP passes #4, #6, #7, and #9 whose approximate locations in the North Atlantic Ocean are shown in Figure 4. The analysis was accomplished in three basic steps:

1. filtering;
2. estimation of the parameters; and
3. graphical presentation of the results.

The basic inputs for the first step are:

1. the altimeter ranges and the exact correlated time of each measurement;
2. the associated orbit ephemeris;
3. the parameters of the reference ellipsoid; and
4. the covariance function for the geoid undulations.

The satellite altimetry data for the four passes were received on magnetic tapes from NASA/JSC. These data consist of eight altimeter range observations in frames at 1.04 second intervals. However, for the purpose of this investigation, the mean of the eight observations in each frame is considered as one observation. This assumption should not degrade the results for the following collective reasons:

1. A frame of observations covers an effective area of about 6 km by 13 km, since the ground speed of the Skylab was about 7 km/sec and the radius of the radar foot print was about 3 km;[9] and

2. Considering the accuracy of the altimeter system on board the Skylab, the change in geoid over an area of size 6 km by 13 km would be insignificant.

The Skylab Best Estimate Trajectory (SKYBET) data are also available on a tape at intervals of exactly 1/8 of a second. Only the earth fixed geocentric coordinates of the Skylab and the time of observation are input from these data.

The best available estimates for the shape and size of the geodetic reference ellipsoid are given by:

1. flattening = 1/298.255

2. semi major axis diameter = 6,378,142.0 meters.

This is the same as the reference ellipsoid to which the Marsh-Vincent 1973 geoid is referred.[9] The covariance function for geoid undulation is taken from Tscherning and Rapp.[6] This is a numerical covariance function compatible with the reference ellipsoid chosen for the analysis.

The residual altitudes which are filtered in the first step and the ground truth geoid undulations taken from the Marsh-Vincent geoid map[9] form the input for the second step which is the estimation of the calibration constants and the geoidal parameters. In the third step, the estimated geoid profiles are plotted against time along with the ground truth profiles for easy comparison for shape.

The data in each mode of the altimeter were observed in several submodes, each of which consists of several sub-submodes of observations. The altitude measurement of the satellite above the ocean which is the only geodetic data of interest, comes only from Modes 1, 3, and 5 of the Skylab altimeter.[10] The maximum magnitude of the geoid undulations, referred to the best available reference ellipsoid, is of the order of about 125-150 meters. Therefore, any residual altitude of more than a conservative estimate of 300 meters, is an indication of instrument malfunction in the altimeter measuring system. Consequently, data were processed only for those segments of the passes (#4, #6, #7, and #9) corresponding to modes 1, 3, or 5 where the absolute residual altitude is less than 300 meters. It was found that the altimeter observations suitable for geodetic processing come from submodes 0, 1, and 2 in modes 1 and 5 and from submodes 3, 4, and 5 in mode 3.

The results of the data analysis consist of:

1. a set of bias terms (Table I) recovered for various segments of the four passes; and
2. a set of geoidal profiles.

Examples of these geoidal profiles and their corresponding bathymetry and gravity profiles are shown in Figures 5 through 10. The geoidal profiles consist of:

1. ground truth geoid (dashed lines) used in estimating the bias terms and establishing the scale;
2. geoid profiles computed from the unfiltered data using the computed bias terms (thin lines); and
3. geoid profiles corresponding to the filtered data.

Since the altimetry data were fitted to the ground truth geoid in the determination of the bias terms, any scale error in the ground truth would also result in error in the altimetry geoid. Consequently, any deviation of the altimetry geoid profiles from the ground truth profile will have short periods. In general, the deviation between the two sets of profiles is within about 2-3 meters with the following exceptions: In pass #7 mode 5 (Figure 9) the deviation ranges from 0 to 12 m. In passes #4 and #6 (Figures 6 and 7), the maximum difference is about 12 m in the Puerto Rico trench area.

A close examination of these differences indicates that these extreme deviations occur in areas of special features such as trenches, ridges and sea mounts. Passes #4 and #6 cross the Puerto Rico trench on the west side. Pass #7 mode 5 is along the western edge of the mid-Atlantic ridge while pass #7 mode 3 crosses the Puerto Rico trench at the Eastern end.

These deviations may be due to several causes:

1. Residual errors due to orbit uncertainties
2. High frequency component of the geoid not reflected in the ground truth data
3. Possible (nadir) alignment errors which result in the departure of the sensor field of view from the nadir
4. Influence of sea state, tides and ocean circulation effects
5. Possible inaccuracies in the computation of the ground truth data
6. Errors introduced as a result of scaling these data off small scale world maps.

Most of the systematic errors caused by the above would be absorbed in the bias terms recovered from the data, especially because of the shortness of the segments for which separate bias terms were considered. The short periodic deviations caused by sea-state, tides, ocean circulation effects, etc., would be of the order of about 1-2 m. This leads us to believe that, at least, the larger deviations are due to the short periodic components of the geoid not reflected in the ground truth geoid. This is confirmed by the fact that such deviations occur in the areas of significantly large geoidal features.

Another striking difference noted in these profiles occurs in pass #7 (mode 5) which passes across the Puerto Rico trench (Figure 9). The trench, as indicated by both profiles, differs horizontally by about 30 seconds of time; equivalent to about 240 km. Looking at the gravity anomaly and bottom topography profiles, the altimetry geoid profile appears to be correct. However, further investigations may be needed in order to determine how a gross discrepancy such as this could have occurred.

Crossing of passes #4 and #6 (Figures 6 and 7) over the Puerto Rico trench and land mass area almost at the same place, has provided an ideal opportunity to compare the results to see the consistency of altimeter system in determining the geoid. The overlapping segments of the profiles for these passes are shown superimposed in Figure 8. The agreement between the profiles is excellent. The only deviation at the beginning of pass #4 mode 5, is due to the instrument transient response after switching pulse width, beam width and pointing between modes. This agreement indicates that the altimeter system is very stable and consistent.

From the results and analysis presented thus far, some general comments/observations and conclusions can be made:

1. The procedure described and applied for filtering the altimetry data and for estimating the calibration constants (bias) and geoid undulations has produced very satisfactory and realistic results;
2. The bias terms recovered for different segments of the same pass are significantly different. There appears to be very little or no correlation among the bias terms associated with the same submodes;
3. The agreement between the general slopes of the two geoid (altimetry and ground truth) profiles shows the viability of the altimetry technique in determining the marine geoid;
4. The magnitude of the deviations of the altimetry geoid from the conventional ground truth leads to the conclusion that these deviations are mostly due to the high frequency components of the geoid rather than due to other causes;
5. The Skylab altimetry data analyzed here have provided ample evidence that the altimetry sensor is very sensitive to local geoidal features such as trenches, ridges, and sea mounts;
6. Excellent agreement between the results obtained for the same place at different times shows that the satellite altimetry is precise and self consistent except for bias terms;
7. The correlation between the altimetry geoid and the gravity anomaly and the ocean bottom topography profiles have shown it to be useful in verifying major discrepancies in the conventional geoid. These correlations may also be useful in other applications such as in geology, geophysics, etc.

CORRELATION OF SKYLAB ALTIMETRY WITH BATHYMETRY AND GRAVITY

There are several obvious correlations of the Skylab altimetry-determined geoid with ocean-bottom topography (bathymetry) and surface free air gravity anomalies. Each of Figures 5, 6, 7, 9, and 10 shows examples of these correlations. In Figure 5, the altimeter responded clearly to the variation in topography and gravity anomalies caused by the Blake escarpment (about 5 m in geoidal heights, correlated with 3600 m depth changes and about 100 mgals in free air gravity anomalies). Note that the ground truth geoidal profile did not show such a change. The free air gravity anomalies show, also, some correlations with bottom topography over the continental shelf and Blake Plateau. Unfortunately, there are no gravity data (indicated by +++ on the profiles) taken at the Blake escarpment. Figure 6 shows very strong correlations, over the Puerto Rico Trench, between the altimetry geoid and both the gravity and bathymetry, (about 15 m geoidal height change corresponding to about 6,000 m change in depth and 400 mgal in free air gravity anomalies). Again, note the difference from the ground truth geoid. The altimeter also responded clearly to the land mass as evidenced by the sharp rise over Puerto Rico.

Passes #4 and #6, over the Puerto Rico trench and Puerto Rico land mass, (Figures 6, 7, and 8) provided an excellent opportunity to show the repeatability of the altimeter. The altimeter data also appear to show some changes due to the shallow water as the Skylab approaches the Lesser Antilles. There is also strong correlation between this altimetry geoid and the gravity, while the ground truth geoid is very smooth. Figure 9 (a segment of pass #7) shows a strong correlation with the Puerto Rico trench (this is the eastern end of the trench which is different from those shown in passes #4 and #6). Also the rise in the altimeter geoid correlates well with the rise in topography going toward the Lesser Antilles. However, the ground truth geoid appears to be shifted laterally by about 200-250 km.

The results of a segment of pass #9 are shown in Figure 10, which indicates a smooth geoid over the whole profile. The geoid variations do not conform to the bottom topography and gravity particularly over the continental slope. It does correlate with the ground truth geoid, however, with one exception where the ground truth profile shows a slight dip corresponding to the continental slope. There is also a relative tilt between the altimetry geoid and the ground truth geoid.

In summary, there are pronounced correlations between the altimeter-determined geoid, the topography and gravity anomaly profiles, particularly those corresponding to special earth structures such as the Puerto Rico trench. In many cases, the altimeter appeared to sense many more details in the geoidal surface than those reflected in the ground truth geoid. There are also some correlations with sea mounts or shallow near-surface topographic features. McGoogan, et al [10,11] showed similar correlations with the Puerto Rico Trench and the Mariana Trench. In addition, he showed some correlations with specific sea mounts and the Flemish cap as well as an overall correlation with the ground truth geoid in around-the-world-profile. Our investigation was limited to the data obtained from the four passes discussed in this paper.

The causes of different gravity anomaly values, hence geoidal features, associated with different but similar bottom topographic features are due to variations in the mass distribution in the earth crust and mantle and to the degree of isostatic compensation. In order to realistically determine and evaluate the various deviations associated with the altimetry geoidal passes, more extensive effort is required. Such an effort could entail constructing sub-bottom profiles, based on various density assumptions and additional geophysical data (magnetic, seismic, geologic) and comparing the results with the geoidal profiles.

FUTURE ALTIMETRY APPLICATIONS

As mentioned earlier, the extent of applications of satellite altimetry will depend, to a large extent, on the degree of accuracy achieved in the determination of the geoid. With the GEOS-3 satellite altimeter (launched April, 1975), a 1-5 m geoid accuracy (absolute) is expected. By 1978/1979 another altimeter is being planned to fly on SEASAT with sub-meter expected accuracy in geoid determination.

Future altimetry applications include the following:

Geodesy/navigation. - Any improvement in the determination of the geoid contributes to geodesy and navigation. With an accuracy of ± 1 m in geoid determination, many geodetic objectives can be achieved. The major contributions are in improving the determination of the size and shape of the earth and a unified datum and coordinate system on a worldwide basis. Determination of the figure of the earth, until the present, has depended largely on continental data. Satellite altimetry is certain to change that trend and include the ocean data covering over 70 percent of the earth's surface. The objectives of the new adjustment of the North American Datum (NAD) is 1 m. The NAD is used for many civilian applications such as surveying, mapping, engineering operations, navigation and resource development. The extension of control points and determining their three-dimensional coordinates to offshore areas as well as the determination of national and international marine boundaries must be established in the same system. Accurate knowledge of absolute deflection of the vertical at sea, if combined with marine geodetic control, could provide the orientation required for all national datums. These absolute deflections are important for improving the accuracy of shipboard inertial navigation systems. Knowledge of the geoid to ± 10 cm from altimetry could provide a worldwide reference for the vertical datum which should contribute to investigations of land subsidence.

Gravity field determination. - The gravity field can be derived from satellite altimetry.[12] A global solution of a ± 1 m altimetry geoid could resolve the gravity field to about $1^{\circ} \times 1^{\circ}$ which represents about 180 x 180 geopotential model. This resolution will contribute considerably to improving the geopotential model which is used in determination of satellite orbit and missile trajectories. The altimetry geoid could also provide information on the gravity anomalies which in turn are helpful, when combined with other geophysical data, in exploration geophysics and identification of geological structures.

Mean sea level (MSL). - A ± 10 cm geoid will contribute significantly to MSL determination. Computation of direction and magnitude of MSL slopes and the heights of each ocean relative to the others are important and still unresolved problems. These problems are further complicated because the results of geodetic and oceanographic computations of the parameters involved are different from each other. Determination of heights, directions and magnitude of sea level slopes relative to the continents is a key factor in land and environmental use and in studies of the effect of changes in polar ice caps which affect marine life, meteorology and climate.

Plate tectonics and ocean trenches. - There is a correlation between the geoid/earth's gravity field and geophysical/geological phenomena. Knowledge of these are required in earth and ocean physics studies. Some of these correlations are shown in Skylab data above. To better understand and model this correlation, a knowledge of the fine structures of the ocean geoid is required. These phenomena contribute to a better understanding of continental drift, polar motion and earthquake mechanisms.

Oceanography. - With a ± 10 cm geoid, it is possible to determine the quasistationary departures of the sea surface topography from the geoid.[13] The departures of the sea surface topography from the geoid such as those due to tides, barometric pressure, wind, storm surges have practical applications in the determination of ocean dynamic phenomena such as circulation patterns, mass and nutrient transport, ocean tides, and ocean current influences. Most of these phenomena have important roles in monitoring and preserving the environment, in air-sea interaction and in global numerical weather prediction.

If the above parameters can be referenced to the geoid, satellite altimetry should contribute to their solution on a global basis. For example, sea slopes due to ocean currents could cause local rise of water across the current on the order of 1 meter. Current slopes are proportional to their speed. Therefore, mass transport can be determined. The periodic effect of tides in the open ocean is perhaps on the order of about 1 meter. Its determination is important particularly for the separation of the influence of earth tides. Also barometric pressure could cause variations in the slope of the sea surface up to several meters. Other applications that could be possible are in the prediction of tsunamis (seismic sea wave) and storm surges. These, however, may be detected only if they occur during the pass of the altimetry satellites. Tsunamis amplitudes in the open ocean range, perhaps, from a few centimeters to about 1 meter. They have large wavelengths of the order of several thousand km with about a 1-hour period. Storm surges, which is the local build-up of water due to distant violent storms (such as hurricanes and typhoons), could cause damage and reach wave heights of the order of several meters when they hit coastal areas. Their prediction and direction of movement could be of importance not only for coastal areas but also for maritime ship operations.

The various problems affecting the accuracy of achieving a ± 10 cm geoid must be solved in order to arrive at many of the above applications. The Skylab altimetry experiment, however, has demonstrated proof of concept of geoid determination from altimetry data and that satellite altimetry is a potentially valuable tool having many useful applications. If GEOS-3 and SEASAT achieve their objectives, the impact of altimetry on earth and ocean dynamics studies would be significant.

ACKNOWLEDGEMENT

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REFERENCES

1. Kaula, W. M. (Chairman), "The Terrestrial Environment: Solid Earth and Ocean Physics", Report of a Study at Williamstown, Massachusetts, to NASA, Report NASA CR-1579, April, 1970.

2. Williams, F. L., "Opening Remarks", Proceedings of the International Symposium on Applications of Marine Geodesy, pp xiii - xvii, Marine Technology Society, Washington, D. C., 1974.

3. Fubara, D.M.J., and Mourad, A. G., "Requirements for a Marine Geoid Compatible with Geoid Deducible from Satellite Altimetry", Proceedings of NOAA/NASA/NAVY Conference on Sea Surface Topography from Space, Edited by J. Apel, NOAA TR ERL 228-AOML7, 1972.

4. Mourad, A. G., Gopalapillai, S., Kuhner, M., and Fubara, D. M., "The Applications of Skylab Altimetry to Marine Geoid Determination:, Final Report prepared by Battelle's Columbus Laboratories to NASA/JSC, under contract NAS9-13276, EPN 440, May 1975.

5. Moritz, Helmut, "Advanced Least Squares Methods", Reports of the Dept. of Geodetic Science, No. 175, The Ohio State University, Columbus, Ohio, 1972.

6. Tscherning, C. C., and Rapp, R. H., "Closed Covariance Expressions for Gravity Anomalies, Geoid Undulations and Deflections of the Vertical Implied by Anomaly Degree Variance Models", Reports of the Dept. of Geodetic Science, No. 208, The Ohio State University, Columbus, Ohio, 1974.

7. Fubara, D. M. and Mourad, A. G. "Results of Geodetic Processing and Analysis of Skylab Altimetry Data", Proceedings of the International Symposium on the Application of Marine Geodesy, pp. 301-314, Marine Technology Society, Washington, D. C. 1974.

8. Vincent, S., and Marsh, J. G., "Global Detailed Gravimetric Geoid", Computer Sciences Corporation and NASA/GSFC, Greenbelt, Md., 1973.

9. Marsh, James G., and Vincent, Samir, "Global Detailed Geoid Computation and Model Analysis", GSFC Report No. X-921-74-131, Greenbelt, Maryland, 1973.

10. McGoogan, J. T., Wells, W. T., and Miller, L. S., "Skylab Altimeter Applications and Scientific Results". Paper Presented at the AIAA/AGU Conference on Scientific Experiments of Skylab, Huntsville, Alabama, October 30 - November 1, 1974.

11. McGoogan, J. T., Leito, C. D., Miller, L. S., and Wells, W. T., "Skylab S-193 Altimeter Experiment Performance, Results and Applications", Proceeding of the International Symposium on Applications of Marine Geodesy, pp. 291-300, Marine Technology Society, Washington, D. C., 1974.

12. Gopalapillai, S., "Non-Global Recovery of Gravity Anomalies from a Combination of Terrestrial and Satellite Altimetry Data", Reports of the Department of Geodetic Science, #210, The Ohio State University, Columbus, Ohio, July, 1974.

13. Apel, J. R., and Byrne, H. M., "Oceanography and the Marine Geoid", Proceedings of the International Symposium on Applications of Marine Geodesy, pp. 59-66, Marine Technology Society, Washington, D. C., 1974.

TABLE I. - RESULTS OF THE BIAS RECOVERY FROM ALTIMETRY DATA

Pass	Mode	Submode	Submode*	Constrained Bias(m) Filtered
4	1	0	1	-23.26
		1	2	-10.25
		2	3	-12.60
	5	0	7	-28.12
		1	8	- 9.02
6	5	0	1	-24.03
		1	2	-11.63
		2	3	- 3.31
7	1	0	1	-52.43
		1	2	-40.28
		2	3	-79.28
	5	0	7	-63.55
		1	8	-52.38
		2	9	-46.56
	3	3	16	-
		4	17	-88.87
		5	18	-87.39
9	5	0	1	-17.07
		1	2	- 6.07
		2	3	0.62
	3	3	10	-19.99
		4	11	-20.53
		5	12	-18.95
		3	18	-36.95
		4	19	-36.26
		5	20	-34.80

* These numbers are assigned sequentially in each for computational convenience.

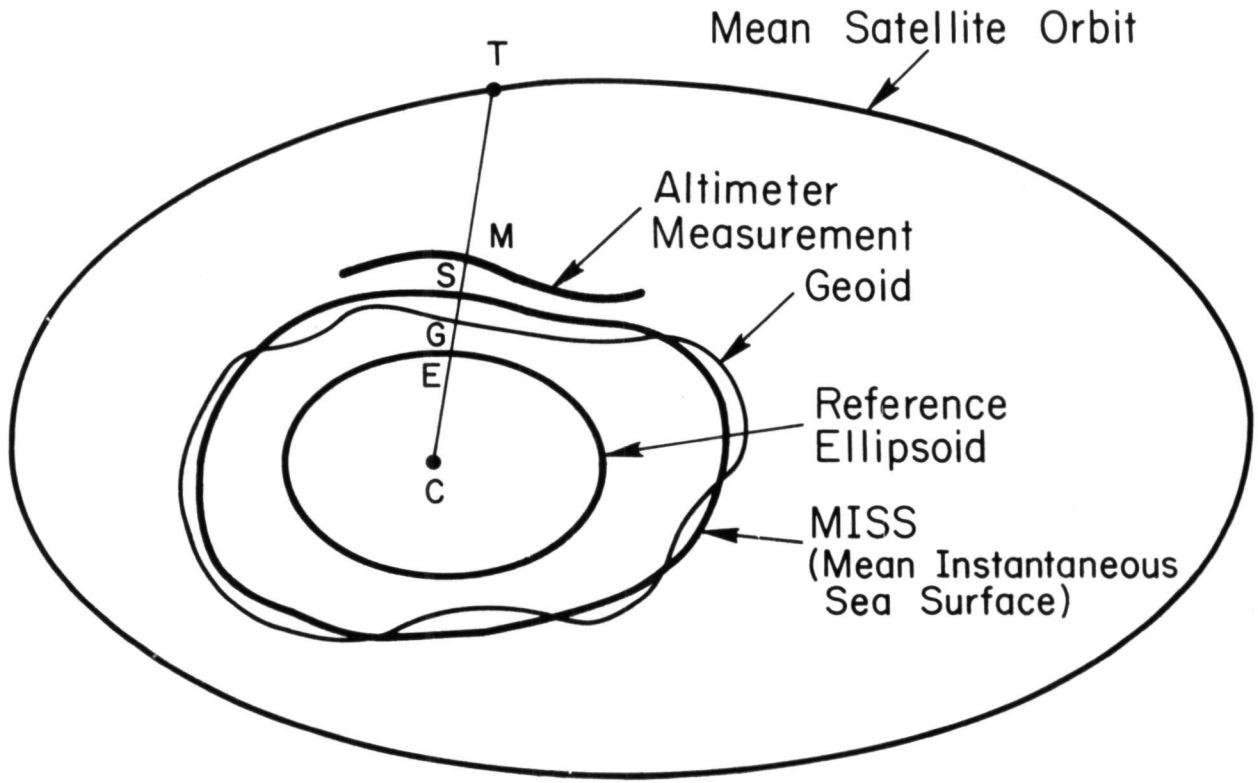


Figure 1. - Surfaces associated with satellite altimetry.

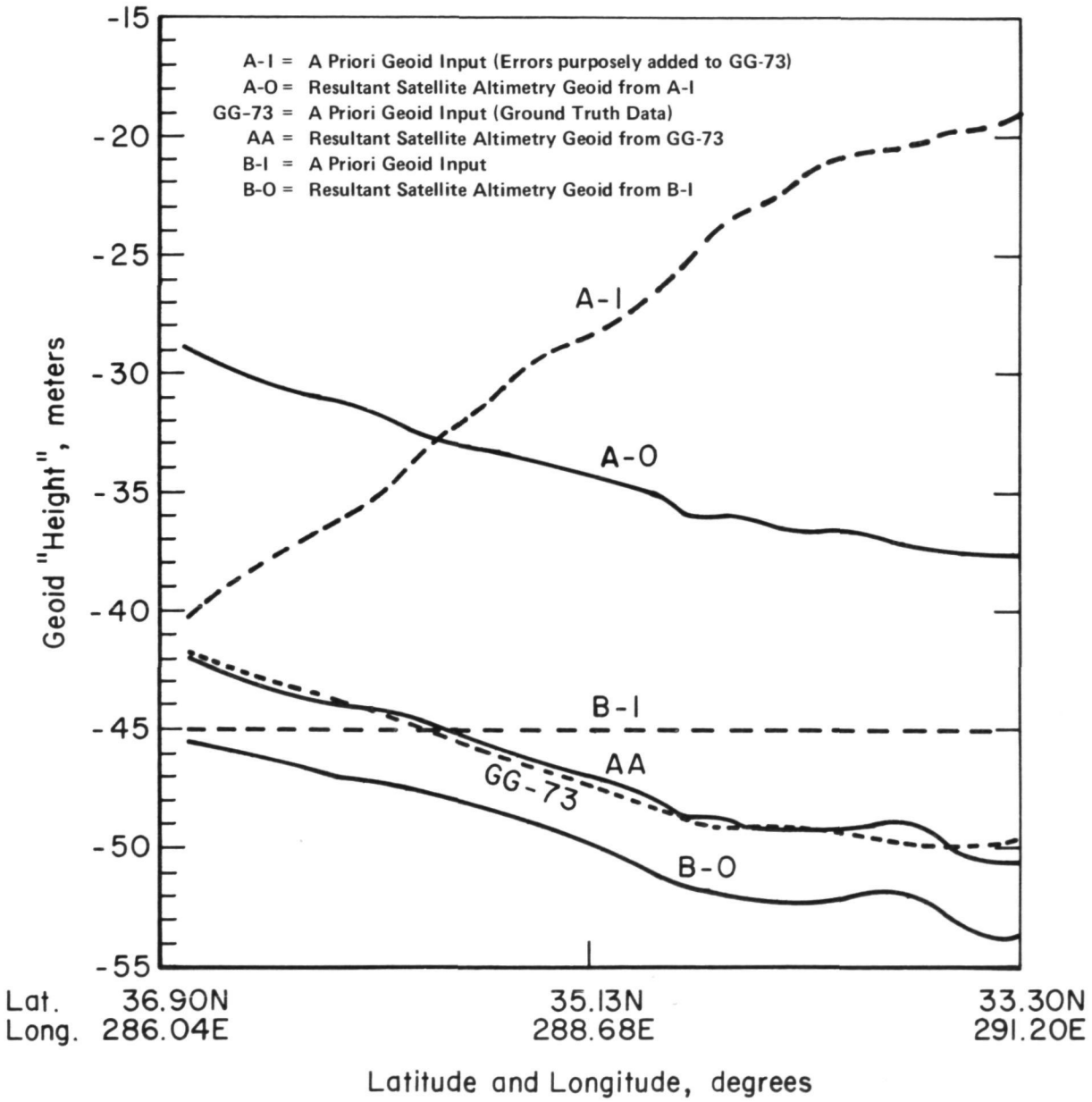


Figure 2. - Effect of errors in a priori geoid height inputs and scale dependency of calibration constant and geoidal height on geodetic control (ground truth).

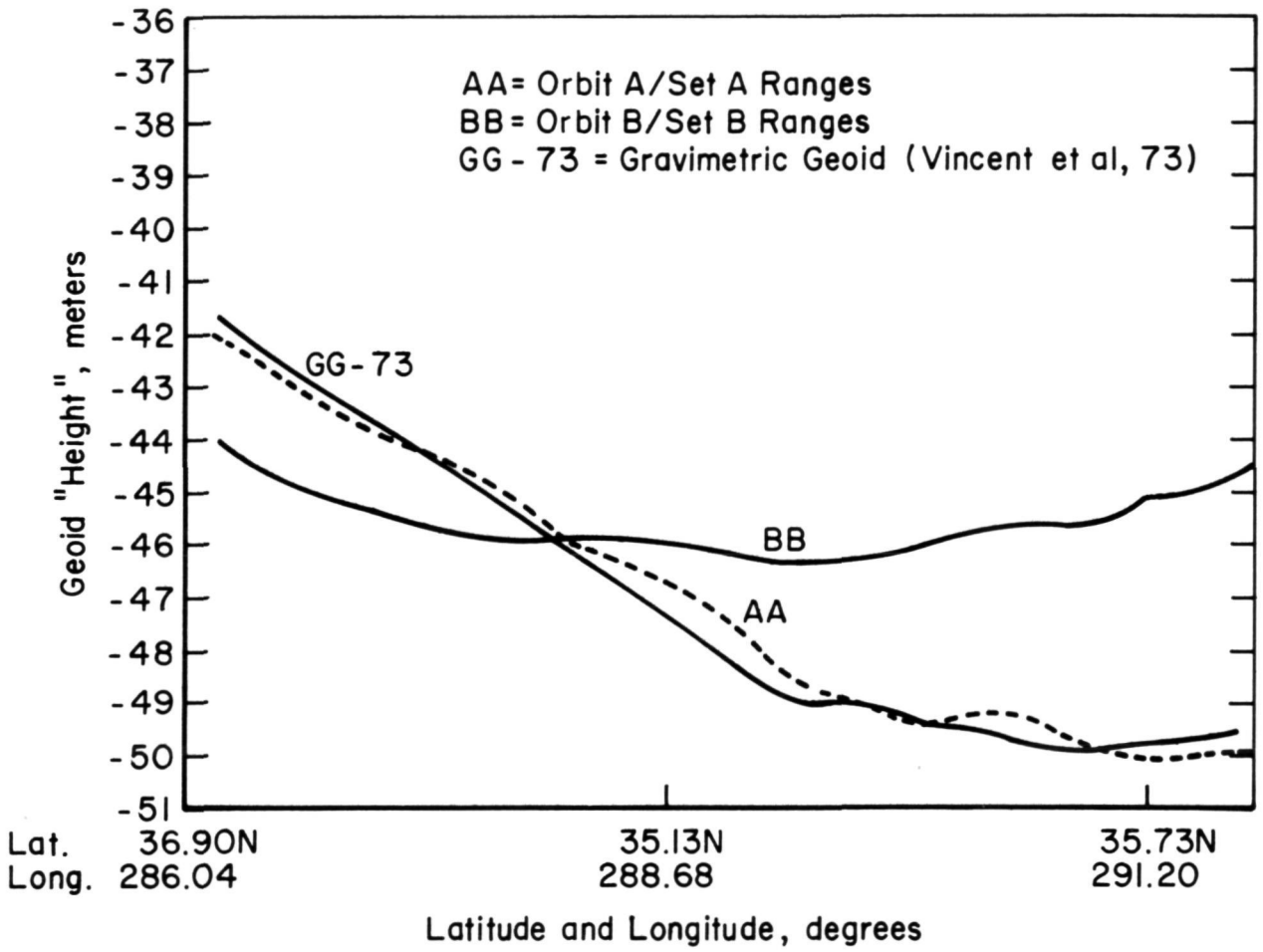


Figure 3. - Conventional Geoid and Satellite Altimetry Geoid Segments (Skylab SL-2 EREP Pass 9 Data)

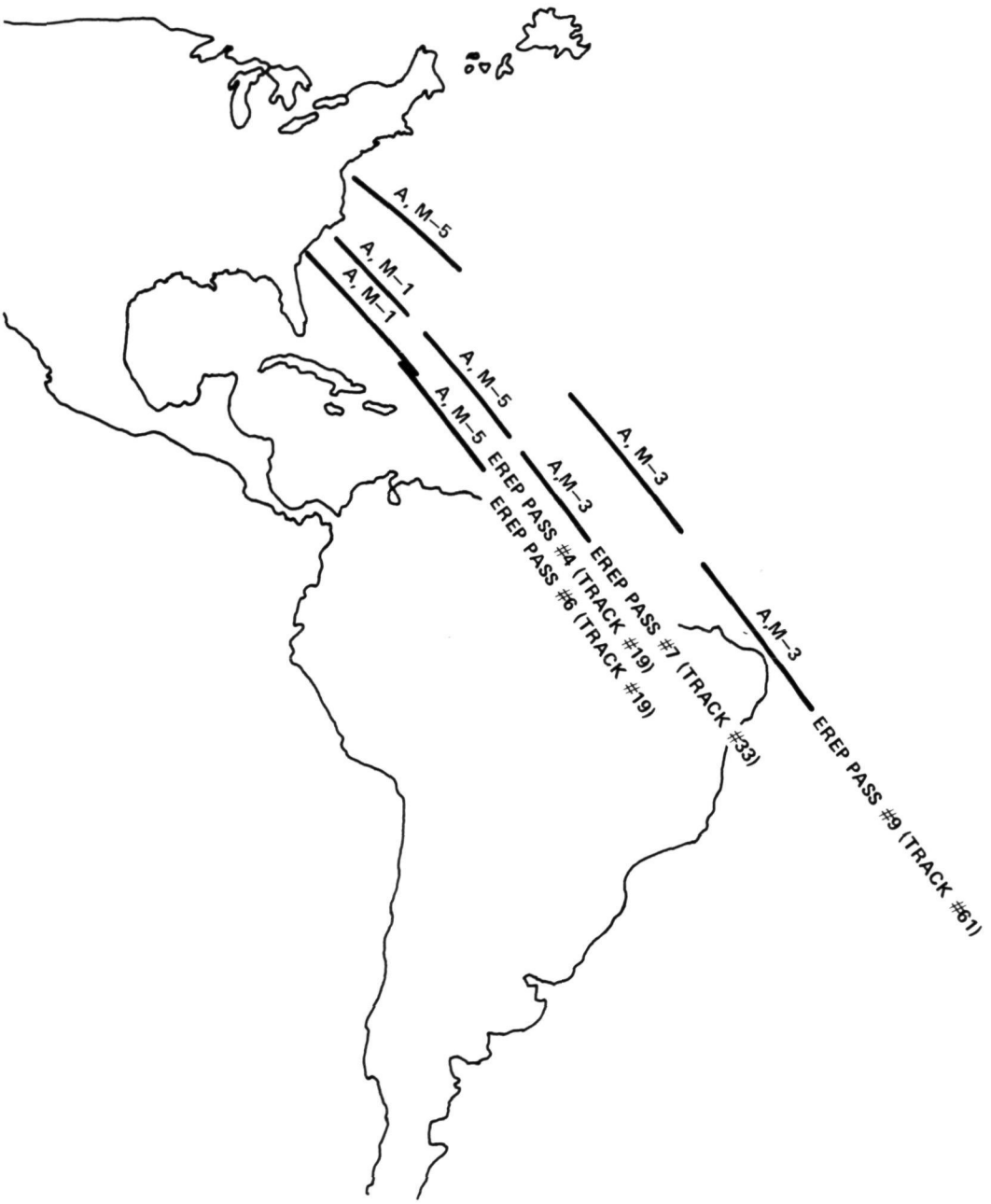


Figure 4. - S193 - Skylab SL-2 data tracks altimeter modes 1, 3, and 5.

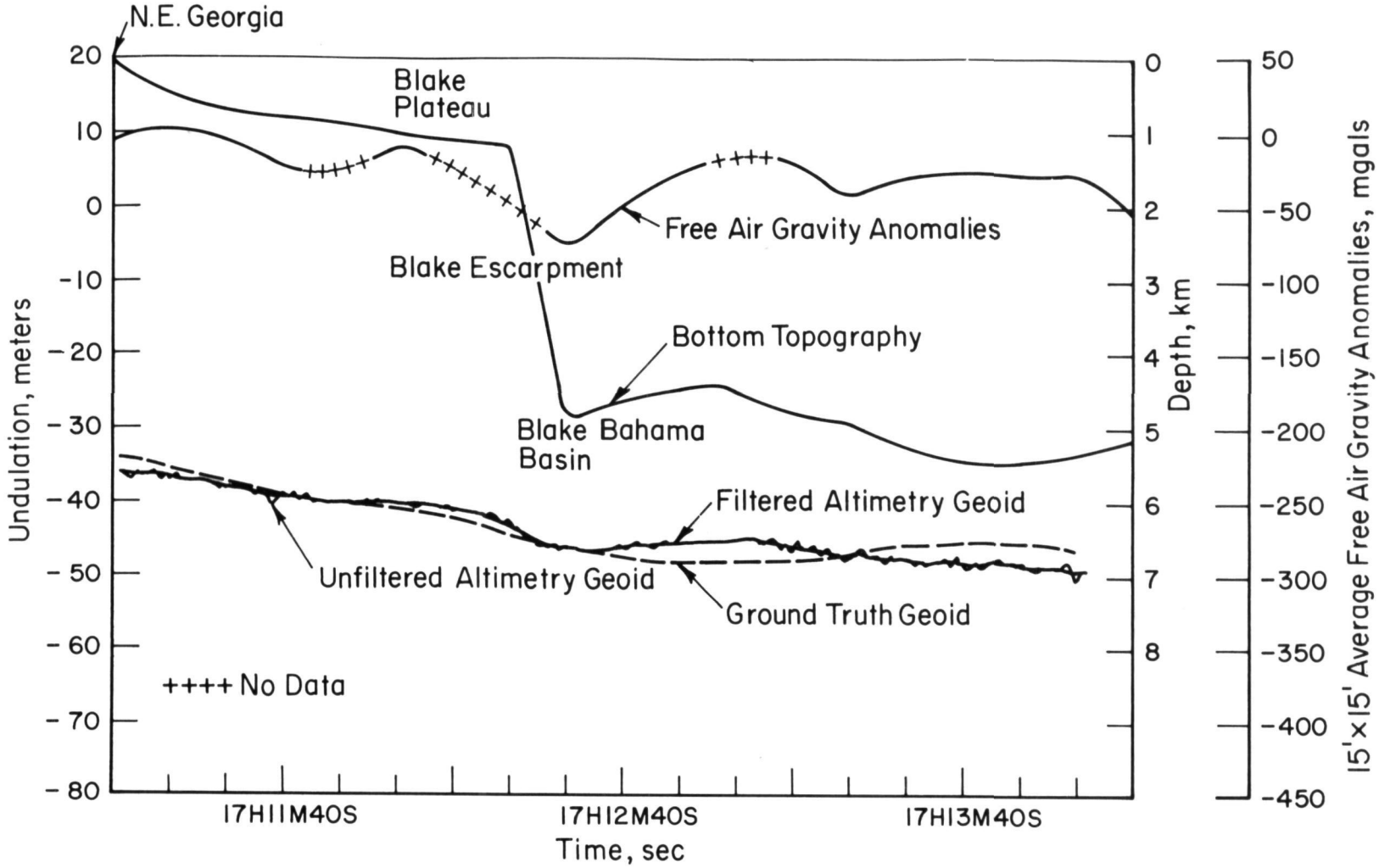


Figure 5. - Geoid undulations computed from Skylab pass-4 altimetry data-mode 1.

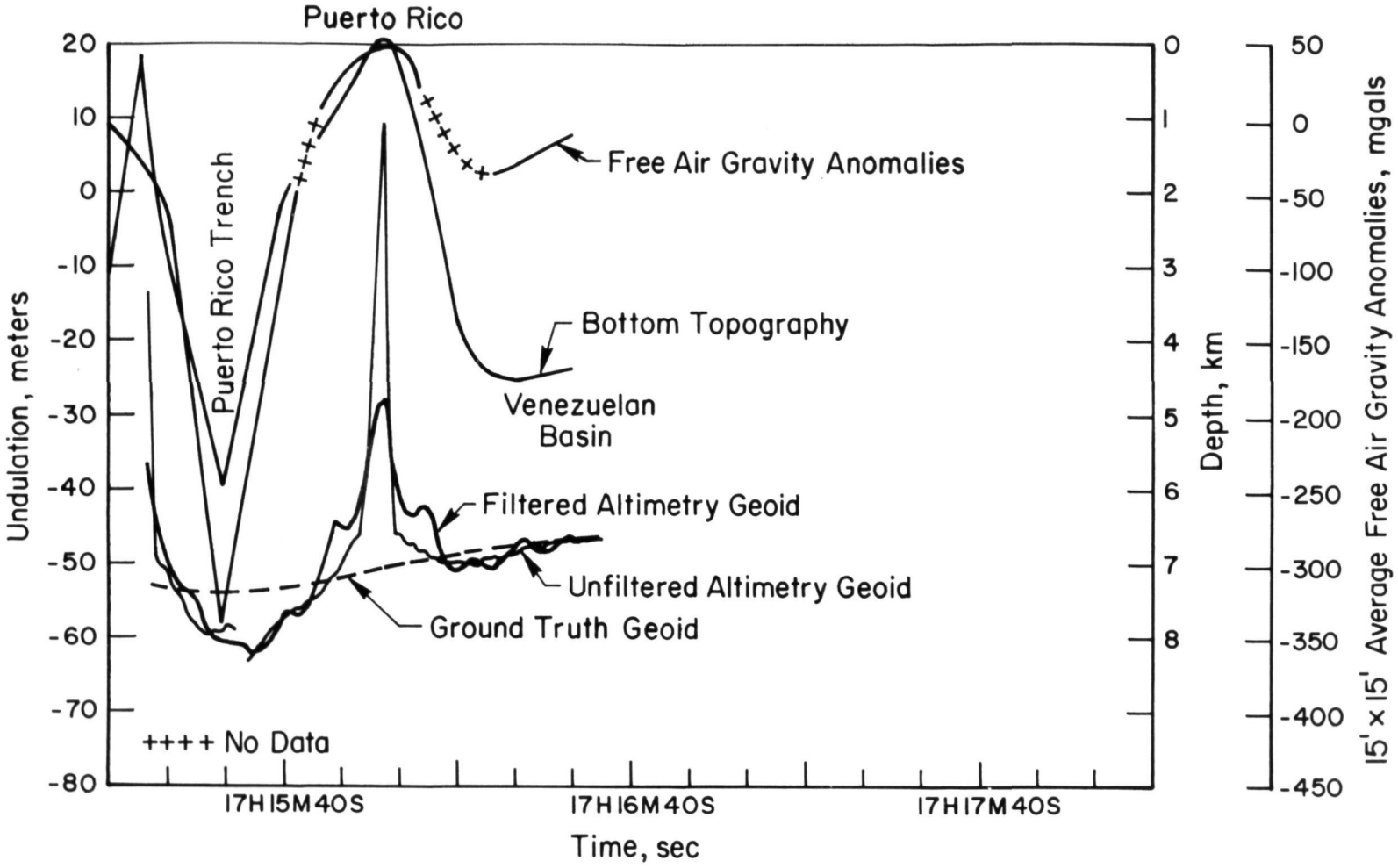


Figure 6. - Geoid undulations computed from Skylab pass-4 altimetry data-mode 5.

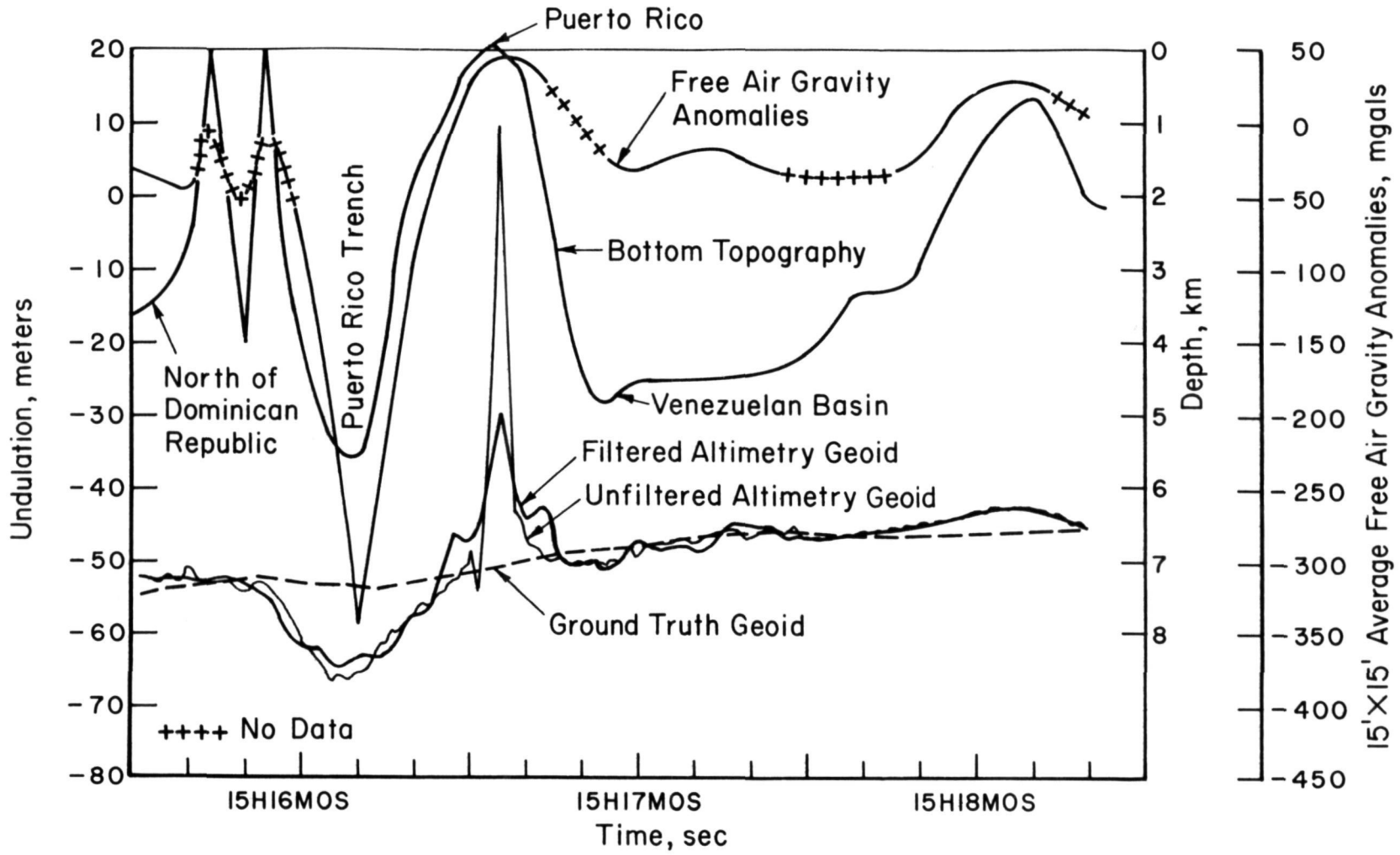


Figure 7. - Geoid undulations computed from Skylab pass-6 altimetry data-mode 5.

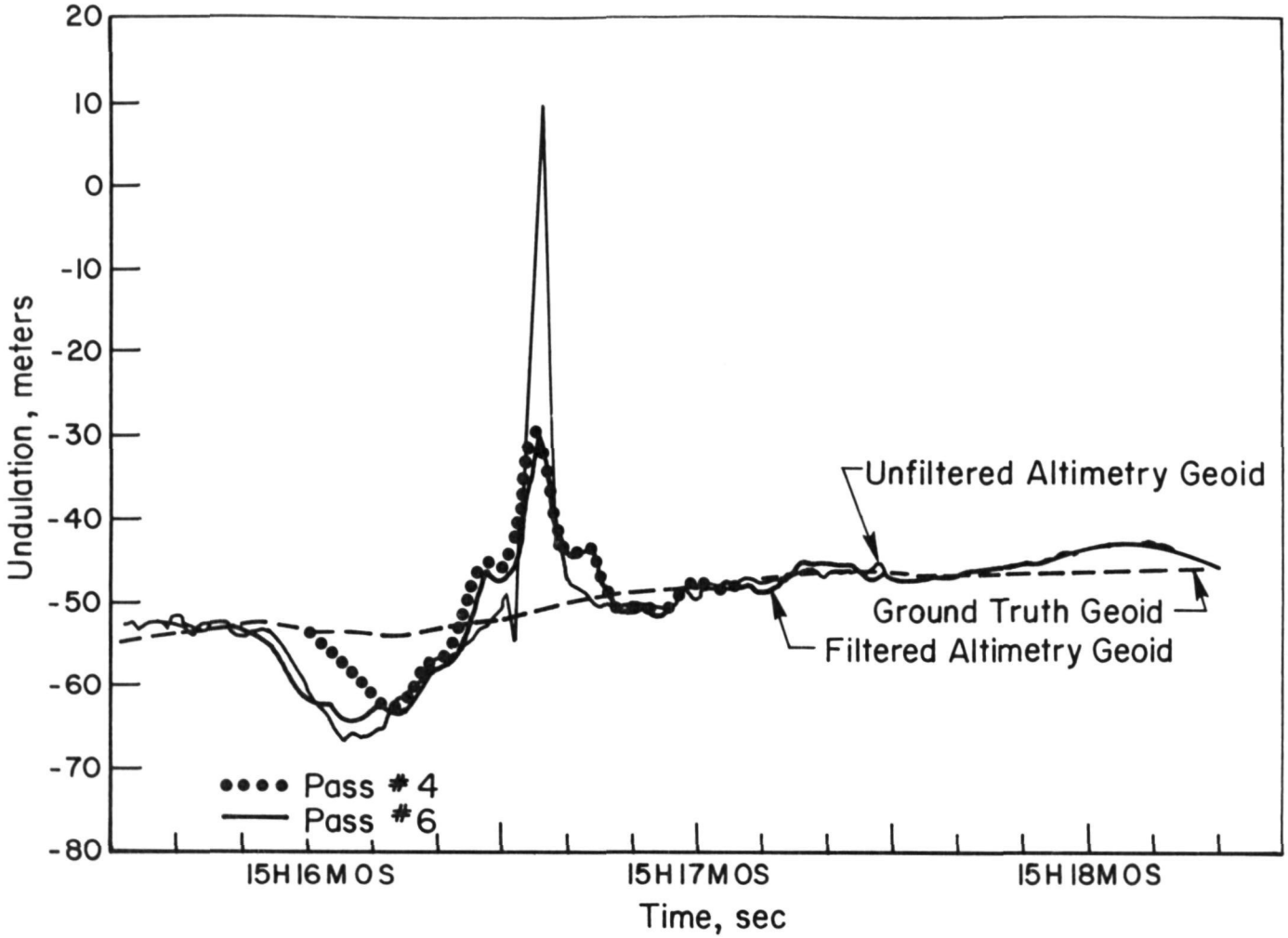


Figure 8. - Comparison of the altimetry geoid profiles over the Puerto Rico trench and land mass as obtained in passes 4 and 6.

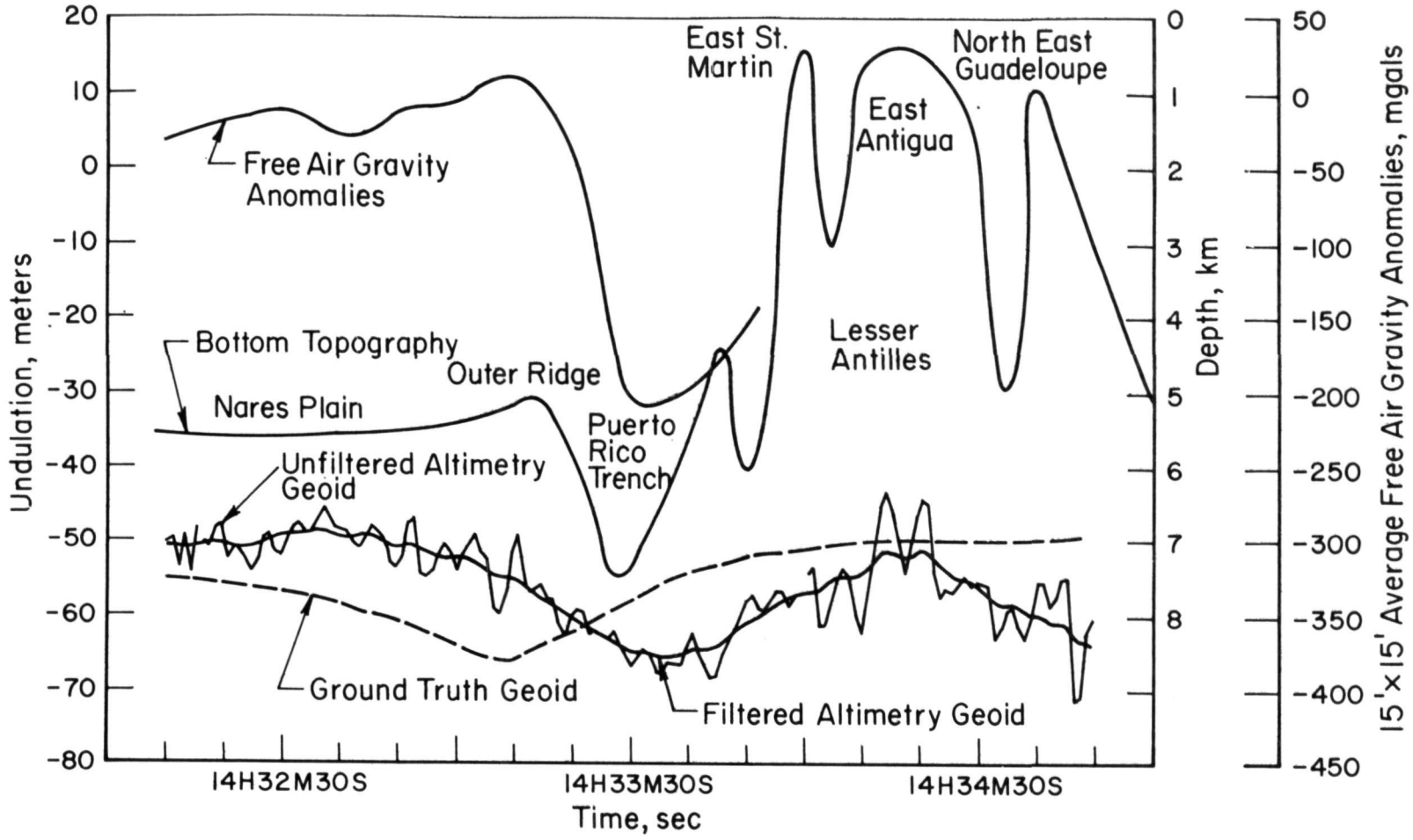


Figure 9. - Geoid undulations computed from Skylab pass-7 altimetry data-mode 5.

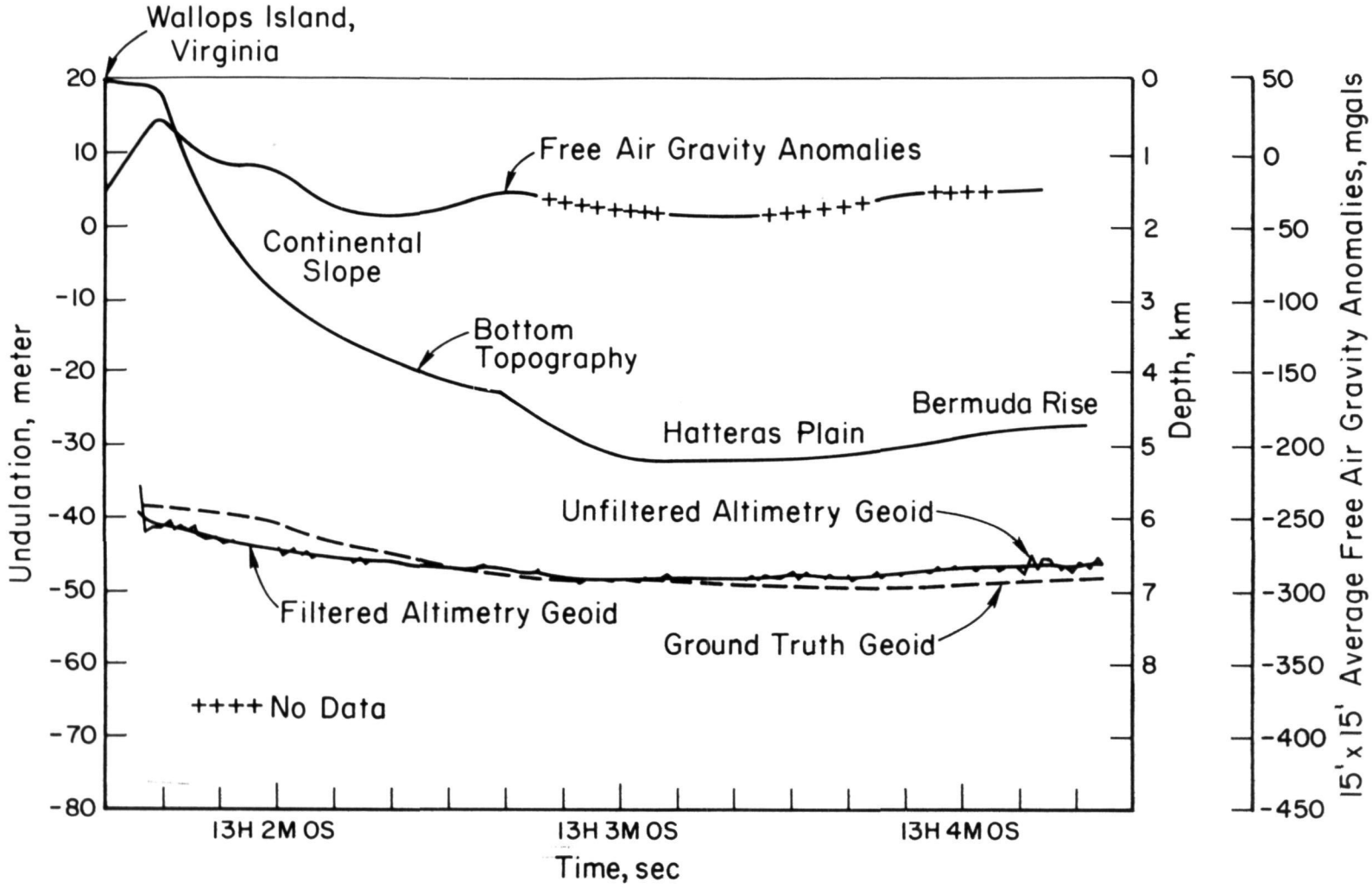


Figure 10. - Geoid undulations computed from Skylab pass-9 altimetry data-mode 5.

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A COMPARISON OF SKYLAB S-193 AND AIRCRAFT VIEWS OF SURFACE ROUGHNESS AND A LOOK TOWARD SEASAT

M-2

By Duncan Ross, Sea-Air Interaction Laboratory, National Oceanic and Atmospheric Administration, Atlantic Oceanographic and Meteorological Laboratories, Miami, Florida

ABSTRACT

An extensive aircraft underflight program was conducted along the Skylab groundpath for the purpose of documenting wind, wave, and atmospheric conditions affecting the amplitude of the active and passive microwave signatures. The S-193 microwave system senses a roughness parameter at the ocean surface that is proportional to the surface windspeed. The exact relationship between the wind and this roughness parameter is the subject of continuing investigations.

In the case of the active portion of the system, the intensity of off-nadir backscatter from the ocean is thought to be primarily determined by the amplitude of short gravity/capillary waves and has been shown to be strongly a function of azimuth relative to the surface wind direction. The passive side of the instrument senses the naturally emitted (and reflected) microwave energy and is proportional to the RMS slope and percent foam coverage of the ocean.

NOAA, NASA, and USAF aircraft were equipped with a variety of environmental sensors in an attempt to specify the surface conditions affecting the satellite sensors as well as active and passive microwave sensors intended to calibrate the Skylab instrument. The aircraft program is described, and some comparisons of satellite and aircraft results are presented. The principal result of the comparison of active radar is that direct inferences of the surface windspeed are possible, but subject to considerable scatter, and that this scatter appears to be due to interaction between long gravity and short Bragg waves and backscatter due to rain as well as errors in correcting for azimuth dependence. It is shown that σ_0 for incidence angles of $\approx 50°$ increases both with windspeed and with increasing energy level of the high-frequency gravity waves that, themselves, are proportional to both the local wind and fetch in a manner that is not uniquely determined by the windspeed.

An unforeseen opportunity to observe a Pacific hurricane by both Skylab and NOAA aircraft has contributed to the development of a simplified wave forecasting scheme applicable to hurricanes, and more general conditions, which combines the better qualities of both spectral and height/period forecasting techniques. The implication of this result to the SEASAT program is that quite large data inputs in both the time and space domain can be handled using existing computers and should produce a forecast of comparable or superior quality to existing spectral techniques, but in shorter time steps. Horizontal polarization data obtained by the aircraft in Hurricane Ava, and in other experiments, which led to this development are presented.

INTRODUCTION

The S-193 experiment aboard Skylab was intended to test the concept of remote determination of surface wind conditions on a worldwide basis as an aid to improved environmental forecasts. A part of this experiment included an aircraft underflight program to calibrate and validate the inference of surface wind conditions from the satellite measurements of radar backscatter, σ_0, and upwelling naturally emitted microwave energy, T_a.

A number of significant developments have evolved as a result of this combination of satellite and aircraft studies of the environment, which will be touched upon herein. It is impossible, however, to discuss in depth all aspects included in the scope of this program. Results presented here are preliminary, and some conclusions may be modified as additional data sets are considered. The reader is, therefore, asked to be tolerant of missing details and tentative conclusions that, hopefully, will be firmed up in future reports.

AIRCRAFT INSTRUMENTATION

The aircraft measurements were obtained from instrumented NOAA, NASA, and USAF C130 aircraft. All aircraft were equipped with a basic environmental package consisting of an inertial platform for windspeed determination, a Barnes Infrared Radiometer for sea surface temperatures, a laser wave profiler for wave measurements, a Cambridge Dew Point Hygrometer, a Rosemount Air Temperature Probe, and a vertical camera for white-cap photography. The NOAA C130 was additionally equipped with a three-frequency passive microwave system at K_u (14.5 GHz), X (8.35 GHz), and L (1.8 GHz) bands. This system was used for dual polarization measurements at X and K_u bands and horizontal polarization measurements at L-band. Because the NOAA aircraft was not available for the third launch period, a cooperative arrangement with the Air Force 53rd Weather Reconnaissance Squadron of the Air Weather Service was negotiated by NOAA, and the inertial platform, laser, microwave, and camera systems were transferred to the Air Force C130 for the SL-4 underflight program. Figure 1 shows the NOAA C130 aircraft with passive microwave antennas extended to the in-flight operating position.

The NASA JSC C130 aircraft was similarly equipped except that the microwave system was both active and passive (time-shared) and centered only at 13.5 GHz. The NASA aircraft participated in the underflight program during all three launch periods.

SATELLITE INSTRUMENTATION

Skylab S-193 Instrument. The S-193 experiment aboard Skylab consists of an instrument capable of operation in one of three modes: (1) short pulse altimetry, (2) radar backscatter, and (3) a passive radiometer mode. The instrument is a single-frequency device centered at 13 GHz (K_u band). In the so-called RADSCAT configuration, the instrument alternately switches between the active and passive mode. It is capable of scanning in the along-track and across-track directions, and thus obtains dual polarization measurements of radar backscattering cross section, σ_0, and

upwelling naturally emitted microwave energy, which is directly proportional to the apparent, or antenna, temperature T_a, as a function of incidence angle.

Radar Backscatter. The mechanisms responsible for determining the level of radar energy backscattered by the ocean surface are primarily, but not limited to, the amplitude of resonant Bragg waves for incidence angles between about 30° and 80°, and the RMS slope distribution for near vertical incidence angles (Wright, 1968; Valenzuela, 1968). The Bragg condition is defined as

$$\frac{2\pi}{\lambda_{water}} = K_B = K_0 \cos \theta_1 + K_0 \cos \theta_2$$

where θ_1 and θ_2 are the incident and scattering angles, $K_0 = 2\pi/\lambda$ microwave. In the case of S-193, these waves correspond to cm wavelength ocean waves. The detailed behavior of Bragg waves and also their effect on backscatter has been the subject of considerable study in laboratory experiments in recent years (cf. Rouse and Moore, 1972; Duncan, Keller, and Wright, 1974; Keller, Larson, and Wright,1974; Keller and Wright, 1975; Reece and Shemdin, 1974; and many others). The principal result of these studies is that the backscattered doppler radar spectrum for a particular radar frequency and incidence angle is not a unique function of windspeed but rather is, to some degree, a function of fetch, duration, and presence of swell as well as windspeed.

The Wave Spectrum. It has been suggested that the S-193 RADSCAT data are affected by both long and short ocean waves. In the following sections, an attempt will be made to evaluate S-193 data in terms of the wave spectrum. A brief description of the spectrum and its behavior during growth and swell situations is therefore appropriate.

Wave conditions can be fully described by the two-dimensional energy spectrum, $A^2(f,\theta)$, and integration over direction (θ) and frequency, f, yields the total energy

$$E = \int_0^\infty \int_{-\pi}^{\pi} [A(f,\theta)]^2 \, d\theta df$$

which is proportional to mean surface displacement, $2\sigma^2$.

For a wind blowing off a shoreline, the fetch is defined simply as the distance from shore to the downwind measurement site. Figure 2 presents the behavior of the one-dimensional energy spectrum for seven fetch locations during offshore wind conditions as observed in the JONSWAP experiment (Hasselmann et. al., 1973). The inset of Figure 2 depicts the meaning of the five parameters suggested by Hasselmann et. al. as convenient for describing the important characteristics of the spectrum. It can be seen from this figure that the peak frequency, f_m, grows and migrates toward lower frequencies as fetch increases. Hasselman et. al. found that the sharpness parameter, γ, and the width parameters σ_a, σ_b, are essentially independent of fetch. The Phillips parameter, α, however, generally decreased with increasing fetch. The behavior of the spectral scale parameters can also be represented

conveniently in nondimensional form by incorporation of the local windspeed, U_{10}, and gravity. Thus, Figure 3 presents the behavior of nondimensional energy

$$\tilde{E} = \frac{Eg^2}{U_{10}{}^4}$$

and nondimensional frequency

$$\tilde{f}_m = \frac{f_m U_{10}}{g}$$

versus nondimensional fetch

$$\tilde{X} = \frac{xg}{U_{10}{}^2}.$$

Nondimensionalization in this manner has properly accounted for the windspeed dependence of the behavior of total energy and peak frequency with fetch. The interrelationship between α, $\tilde{E}$, and $\tilde{f}_m$ is therefore apparent and was studied in detail by Hasselmann et. al. (1975). They proposed $\tilde{f}_m$ as a convenient means of describing the stage of development of the wave spectrum in an average sense. Figures 4 and 5 from this study show the behavior of $\tilde{E}$ and α with respect to $\tilde{f}_m$ and $\tilde{X}$. The lines denoted

$$C_\omega = 10^{-3}$$

and

$$C_\omega = 10^{-5}$$

are representative of the momentum entering the wave field (Hasselmann et. al., 1973), with an approximate mean value of

$$C_\omega \approx 10^{-4},$$

or about 20 percent of the total momentum transferred to the ocean by the wind. Variations about the mean are attributed to changes in the local wind conditions. An example of varying the wind by a factor of 1.5 for a particular f_m is included in the figures.

RESULTS

Because the principal purpose of the S-193 experiment was to remotely infer surface wind conditions, it is appropriate to first consider examples of the data from a typical pass as a prelude to more extensive analysis of the complete data set. Figure 6 presents the results of a pass in the Gulf of Mexico during SL-2 and is a typical example of variable low windspeed conditions. The S-193 active radar backscattering cross sections, (σ_0), and passive microwave antenna temperature, T_a, for horizontal polarization and an incidence angle of 50° are shown plotted as a function of latitude along with the surface wind conditions as determined from the NOAA aircraft underflight.

Considerable variability can be seen for σ_0, especially around 19° and 22° N. The data for those latitudes less than 23°, however, were not corrected for azimuth dependence and therefore show scatter due to changes in wind direction as well as speed. The higher latitudes, however, are of most interest because they were accompanied by extensive ground truth. It can be seen that the surface winds decreased significantly between 24° and 26° N, while σ_0 decreased only slightly between 24° and 25.5° N and actually increased at 26° N. The horizontally polarized antenna temperature agrees well with aircraft determinations and also increases significantly at 26° N. Because of the presence of many rain showers observed by the aircraft to be in the area of 26° N, these increases are tentatively attributed to this factor. This pass, therefore, implies significant corrections would normally be required to account for the presence of rain.

During SL-2, a unique opportunity to observe high wind conditions developed with the appearance of a hurricane in the eastern Pacific southwest of Acapulco, Mexico (Ross et. al., 1974). As plans were being formulated for observing the storm with the S-193 system, the NOAA C130 aircraft deployed on the 6th of June to Acapulco, refueled, and flew a 7.5-hour mission into the storm. Figure 7 is a NOAA-2 composite satellite view of Hurricane Ava showing the flight track of Skylab as it conducted a data pass with S-193 operating in the side-looking solar inertial mode. Unfortunately, the storm was rapidly moving away from the subsatellite track and it was not possible to obtain measurements in the region of maximum winds. Figure 8 is an example of active and passive measurements of Ava obtained at incidence angles of 42.5° and 50.5° along with estimates of surface winds obtained during the aircraft penetration and rainfall rates estimated from the NIMBUS-5 satellite 19.35 passive microwave system (Wilheit, 1972). It can be seen from this figure that there is an increase in σ_0 and T_a in the higher wind areas of the storm with the highest antenna temperature occurring in the zone of heavy rainfall.

High wind conditions were also obtained during the third launch period. Figure 9 shows the subsatellite track for data obtained on the 9th of January at incidence angles of 0° and $\pm \approx 50°$ along with the NOAA surface analysis for 1800Z. This situation is particularly interesting because the windspeed varied from 7.5 to 30 m/sec from the beginning to the end of the sampling period with little rainfall reported except in the region of the front. Figure 10 presents the variation in σ_0 and T_a for +47.6° and -50.5° incidence angle along with surface winds estimated from an isotach analysis based mainly on ship reports and the NASA JSC aircraft measurements. A qualitative comparison of these data sets, together with that from Hurricane Ava and the June 11 pass in the Gulf of Mexico, strongly suggests a first-order dependency on surface wind conditions but with scatter.

Unfortunately, due to damage to the S-193 antenna occurring during an SL-3 extravehicular excursion, the antenna pattern was altered in an unknown fashion. It is therefore risky to include the 9 January data set with those obtained during SL-2 when calculating windspeed dependency. This case was therefore treated separately and is shown plotted against windspeed in Figure 11. σ_0 and T_a data obtained during SL-2 are shown in Figure 12 plotted against windspeed. These data sets are restricted to those data passes described above, which were accompanied by an aircraft underflight. Aircraft-determined antenna temperatures included show good agreement with S-193. The surface winds attached to each satellite data point are judged to be accurate to about 1 to 3 m/sec in the case of SL-2 and 3 to 5 m/sec in the case of the SL-4 pass of 9 January. The judgment of accuracy includes the effects of mesoscale variability in the local wind conditions and inaccuracies associated with aircraft-determined winds and ship reports in the case of

the 9 January data. Unfortunately, no study is known to the author that compares ship reports (mostly visual estimates) to continuously recorded and calibrated winds averaged over 10 to 30 minutes. Therefore, one is left with a judgment.

DISCUSSION

The above data sets strongly suggest a useful first-order relationship between surface winds for both σ_0 and T_a subject to some degree of scatter. There are several sources of errors in both parameters contributing to the scatter that crops up in the processing. In addition, there may be errors due to invalid atmospheric assumptions (or errors in the corrections required for a particular assumption), random errors in inferring the 10-meter windspeed from aircraft measurements, as well as natural variability in local wind conditions. The above errors inherent to this data set probably cannot be reduced any further.

One potential source of error that can be addressed, however, lies in the lack of uniqueness of the active or passive signature due to the variability in possible wave conditions that may be present for a given windspeed. Reece and Shemdin (1974), in a study conducted in a wave tank, showed that the high-frequency waves, for a particular fetch, are windspeed dependent, but the absolute energy level for a particular windspeed is reduced with the addition of a low-frequency component (swell) and that the amount of the reduction is proportional to the amplitude of the low-frequency component. Mitsuyasu (1971) showed similar reduction in the high-frequency gravity region of the wave spectrum with the introduction of swell. Hasselmann et. al. (1973), showed that the Phillips constant (α) (Phillips, 1958), which determines the energy level of the f^{-5} region of the wave spectrum, decreases with increasing nondimensional fetch as discussed earlier. In order to assess the possible importance of the gravity wave spectrum in this data set, it is desirable to consider σ_0 as a function of some observable parameter of the wave field that varies with fetch in a well-behaved and predictable manner.

The nondimensional peak frequency, $\tilde{f}_m$, was shown earlier to be a particularly useful parameter that well describes the stage of development of the wave spectrum. Aircraft measurements of the wave spectrum were used directly to specify f_m for Skylab data sets obtained on 5 and 11 June 1973. The data for Hurricane Ava, however, present a special problem because the aircraft measurements were not obtained at the exact subsatellite point. In order to specify the peak frequency, it was desirable to develop some technique of estimating these parameters from the aircraft data set. The hurricane wind fields are circular in nature, however, and the fetch relationship needed to infer $\tilde{f}_m$ is ambiguous and arbitrary. Furthermore, the position of the aircraft measurements relative to the eye of the hurricane were concentrated in the rear quadrant, whereas most of the satellite positions were to the right of the hurricane center. Figure 13, however, presents some of the wave data obtained, plotted along with spectra from the North Sea measured under similar wind conditions, but fetch limited, and in the North Atlantic during fully developed conditions. The resemblance between the spectra is striking. The most significant feature of the Ava spectra, however, is the general lack of "swell," which would appear as a secondary peak in the spectrum. This is especially significant when the unidirectional assumption required in processing the aircraft data is considered. Because we assume all waves are moving in a direction parallel to the aircraft flight track, swell from some other direction is moved toward lower frequencies in the mapping process to fixed coordinates, leading to an unrealistic "broad"

appearance to the spectrum with multiple peaks. Hurricane Ava was a superhurricane by any criteria and had a record low pressure for eastern Pacific storms of 914 millibars. Fortunately, another such storm of which wave measurements have recently become available was Hurricane Camille, one of the worst hurricanes to ever strike the coast of the United States as it went ashore near Mobile, Alabama, in August of 1969. Camille's eye dimensions, maximum winds, forward velocity, and central pressure were virtually identical to those of Hurricane Ava. Measurements of wave conditions in relatively deep water were obtained by a consortium of oil companies. Some of the data were reported recently (Patterson, 1974, and Hamilton and Ward, 1974) and were used in this study. Figure 14 presents the relative positions of Camille and Ava wave data to the eye and wind field of Ava as determined from the NOAA aircraft flight. It is fortunate that Camille was so similar to Ava as the windspeeds measured on the oil company platform were biased low because of poor anemometer exposure for a storm approaching in the direction of Camille. Ava's winds were therefore used to specify the Camille wind field, which avoids the difficulty of introducing another empirically based technique to specify 10-meter anemometer winds. The wave data from Camille and Ava were then nondimensionalized and plotted against the nondimensional radial distance from the eye and are presented in Figure 15. It can be seen that a simple power law reasonably well describes the radial behavior of both $\tilde{E}$ and $\tilde{f}_m$. Nondimensional peak frequencies for the Ava data set were therefore calculated from the expression.

$$\tilde{f}_m = 1.6\tilde{R}^{-.25}$$

where

$$\tilde{R} = \frac{rg}{U_{10}{}^2}$$

and r is the particular radial distance from the subsatellite point to the eye of Ava. The Ava data set was then combined with data from 5 and 11 June 1973 and is shown in Figure 16. It can be seen that σ_0 varies considerably with $\tilde{f}_m$. It can be argued that, because the windspeed is included in the calculation of $\tilde{f}_m$, it is difficult to correctly separate the windspeed dependency from stage of development. To aid in this separation of dependencies, a multiple regression analysis was performed according to the equation

$$Z = a_0 + a_1x + a_2y$$

letting $Z = \sigma_0$, $x = U_{10}$, and $y = \tilde{f}_m$. The constants a_0, a_1, and a_2 were found to be -29.5, 0.20, and 59.4, respectively. Such a dependency on $\tilde{f}_m$ is much greater than expected or would be predicted on the basis of wave tank experiments cited earlier. The same multiple regression analysis was performed on the 9 January data set, based on hindcast $\tilde{f}_m$, for 47.6° incidence angle, and yielded values of -15.7, 0.39, and 17.5 for the same constants. The hindcast performed assumed limited fetch, but unlimited duration, and the rather low wave heights reported suggest an underestimate for the values of $\tilde{f}_m$ for the higher winds. Also possible is a bias in the case of the hurricane data set due to backscatter from rain. The 9 January data set, however, seems to confirm a fetch dependency and both sets considered together suggest that controlled high-wind, variable-fetch experiments should be performed to accurately infer high winds from measurements of σ_0.

A similar treatment of the fetch effect in the case of the passive microwave measurements is also indicated and is underway.

RELATION TO SEASAT

The success of the simplified approach suggested by Hasselmann et. al. (1975) for specifying the evolution of the wave spectrum depends on successful parameterization of the nonlinear interactions that control the exchange of energy within the spectrum that, in turn, are very sensitive to local gustiness in the surface wind conditions. However, because it is not necessary to deal with the entire directional spectrum for each grid point in a numerical forecast scheme, it will be possible to increase the density of grid points and decrease the time steps involved in forecasting waves. For example, a typical spectral model consisting of 17 frequencies and 15 directions for 512 grid points in the North Atlantic requires 130 000 storage locations, whereas the simplified approach, expanded to account for two swell systems, can increase the grid density to 5012 and require only 30 072 locations. Such a forecasting approach is needed for rapid assimilation of satellite data and will likely be in operation by the time the SEASAT satellite is launched. At this time, the First Global GARP Experiment will also be underway and provide a unique opportunity to test the SEASAT concept.

CONCLUSIONS

The Skylab S-193 experiment has proved that active and passive microwave sensors can be used to infer surface winds but are subject to scatter and a decreasing sensitivity with increasing windspeed in the case of the active radar, and bias due to rainfall with little sensitivity to lower windspeeds in the case of passive microwave signatures. These results, therefore, suggest that combined active and passive systems with a weighted averaging process (employing polarization dependencies) being used to infer the local wind might reduce some of the scatter due to random errors and should be tested with Skylab data. The results further suggest that a parameterization of the wave spectrum may be necessary in order to further reduce the scatter in σ_0. The Skylab data set contains most of the data needed to test these hypotheses and could lead to satellite determination of both the windspeed and surface wave spectrum by judicious use of active and multifrequency passive microwave systems.

ACKNOWLEDGMENTS

The author is grateful to the many people in the satellite and aircraft program which comprised the Skylab experiment. Special thanks are due the NOAA C130 crew for expertly conducting 500 foot flight tracks in one of the most severe hurricanes of record, and the NASA JSC and USAF air crews for low-level flights into severe winter storms (especially the Air Force loadmaster who finally closed a balky cargo door allowing a planned high-altitude pressurized return to shore during one occasion). Finally, the accuracy and extent of passive microwave data collected by the NOAA and USAF aircraft is due to the diligence and competence of the Naval Research Laboratory and is greatly appreciated.

REFERENCES

Barnett, T. P., and J. C. Wilkerson (1967), On the generation of ocean wind waves as inferred from airborne radar measurements of fetch-limited spectra. J. Mar. Res. 25, 292.

Duncan, J. R., W. C. Keller, and J. W. Wright (1974), Fetch and wind speed dependence of Doppler spectra. Radio Science 9, No. 10, 809-819.

Hamilton, R. C., and E. G. Ward (1974), Ocean data gathering program-quality and reduction of data. Offshore Technology Conference Proceedings, OTC 2108-A, 750-756.

Hasselmann, K., T. P. Barnett, E. Bouws, H. Carlson, D. E. Cartwright, K. Enke, J. A. Ewing, H. Gienapp, D. E. Hasselmann, P. Kruseman, A. Meerburg, P. Muller, D. J. Olbers, K. Richter, W. Sell, and H. Walden (1973), Measurements of wind-wave growth and swell decay during the Joint North Sea Wave Project (JONSWAP), Deutsche Hydrogr. Z., Suppl. A(8°), No. 12.

Hasselmann, K., D. B. Ross, P. Mueller, and W. Sell (1975), A Parametrical Wave Prediction Model, submitted to Journal of Physical Oceanography.

Keller, W. C., T. R. Larson, and J. W. Wright (1974), Mean speeds of wind waves at short fetch. Radio Science 9, No. 12, 1091-1100.

Keller, W. C., and J. W. Wright (1975), Microwave scattering and the straining of wind-generated waves. Radio Science 10, No. 2, 139-147.

Mitsuyasu, H. (1971), Observations of the wind and waves in Hakata Bay. Rep. Res. Inst. Appl. Mech., Kyushu University, 19:37-74.

Patterson, M. M. (1974), Oceanographic Data from Hurricane Camille. Offshore Technology Conference Proceedings, OTC 2109.

Phillips, O. M. (1958), The equilibrium range in the spectrum of wind generated waves. J. Fluid Mech. 4(4), 426-434.

Pierson, W. J., and L. Moskowitz (1964), A proposed spectral form for fully developed wind seas based on the similarity theory of S. A. Kitaigorodskii. J. Geophys. Res. 69, 5181-5190.

Reece, A. M., and O. H. Shemdin (1974), Modulation of capillary waves by long waves. Symposium on Ocean Wave Measurement and Analysis, Amer. Soc. Civil Eng., New Orleans, Louisiana.

Ross, D., B. Au, W. Brown, and J. McFadden (1974), A remote sensing study of Pacific Hurricane Ava. Ninth International Symposium on Remote Sensing of Environment Proceedings, 15-19 April, 163-180.

Ross, D., and V. Cardone (1974), Observations of oceanic whitecaps and their relation to remote measurements of surface wind speed. J. Geophys. Res. 79, No. 3, 444-452.

Rouse, J. W., and R. K. Moore (1972), Measured surface spectrum dependence of back-scattering from rough surface. IEEE Trans. Antennas Propagat., AP-20, 211-214.

Valenzuela, G. R. (1968), Scattering of electromagnetic waves from a tilted, slightly rough surface. Radio Science 3, 1057-1066.

Wilheit, T. (1972), Nimbus-5 Users Guide, NASA Goddard Space Flight Center, Washington, D.C.

Wright, J. W. (1968), A new model for sea clutter, IEEE Trans. Antennas Propagat., AP-16, 217-223.

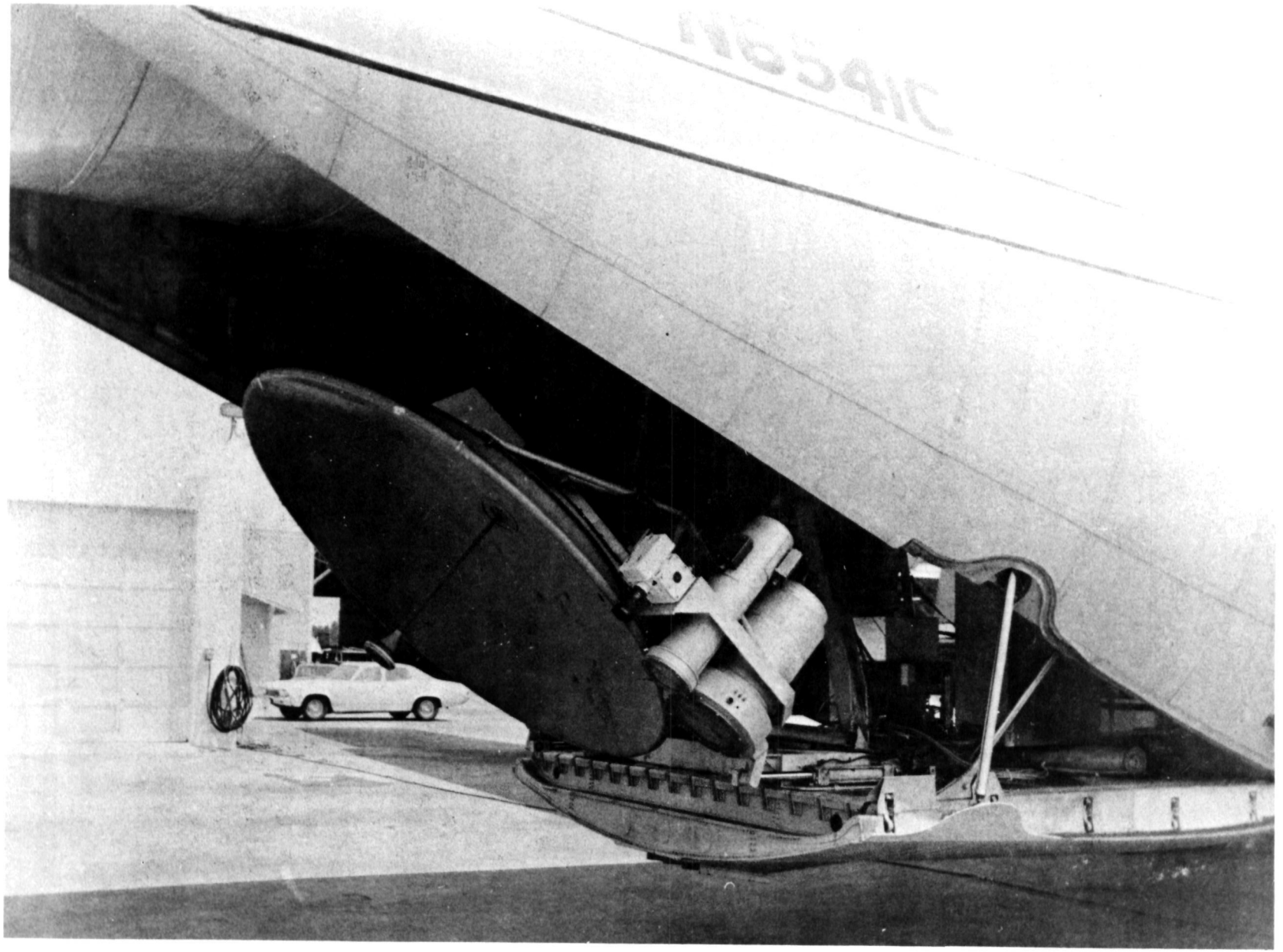


Figure 1. The NOAA C130 aircraft show passive microwave sensors in the extended position.

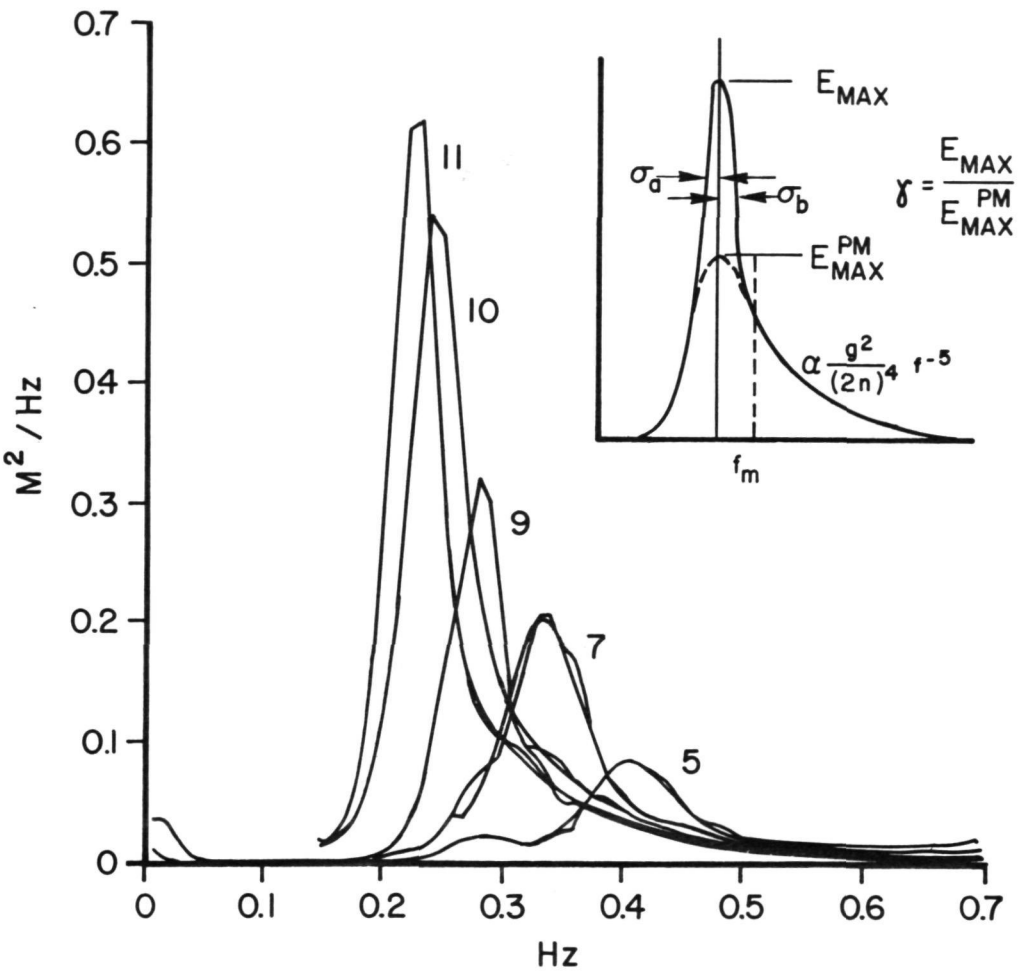


Figure 2. Growth of wave spectra for offshore wind conditions during JONSWAP-69. Fetch increases from Station 5 through Station 11. Three shape parameters σ_a, σ_b, and γ, and the scale parameters f_m and α suggested by Hasselmann are shown in the inset. γ is simply the ratio of the energy at f_m to that which would be predicted by the Pierson-Moskowitz (1964) form of the spectrum.

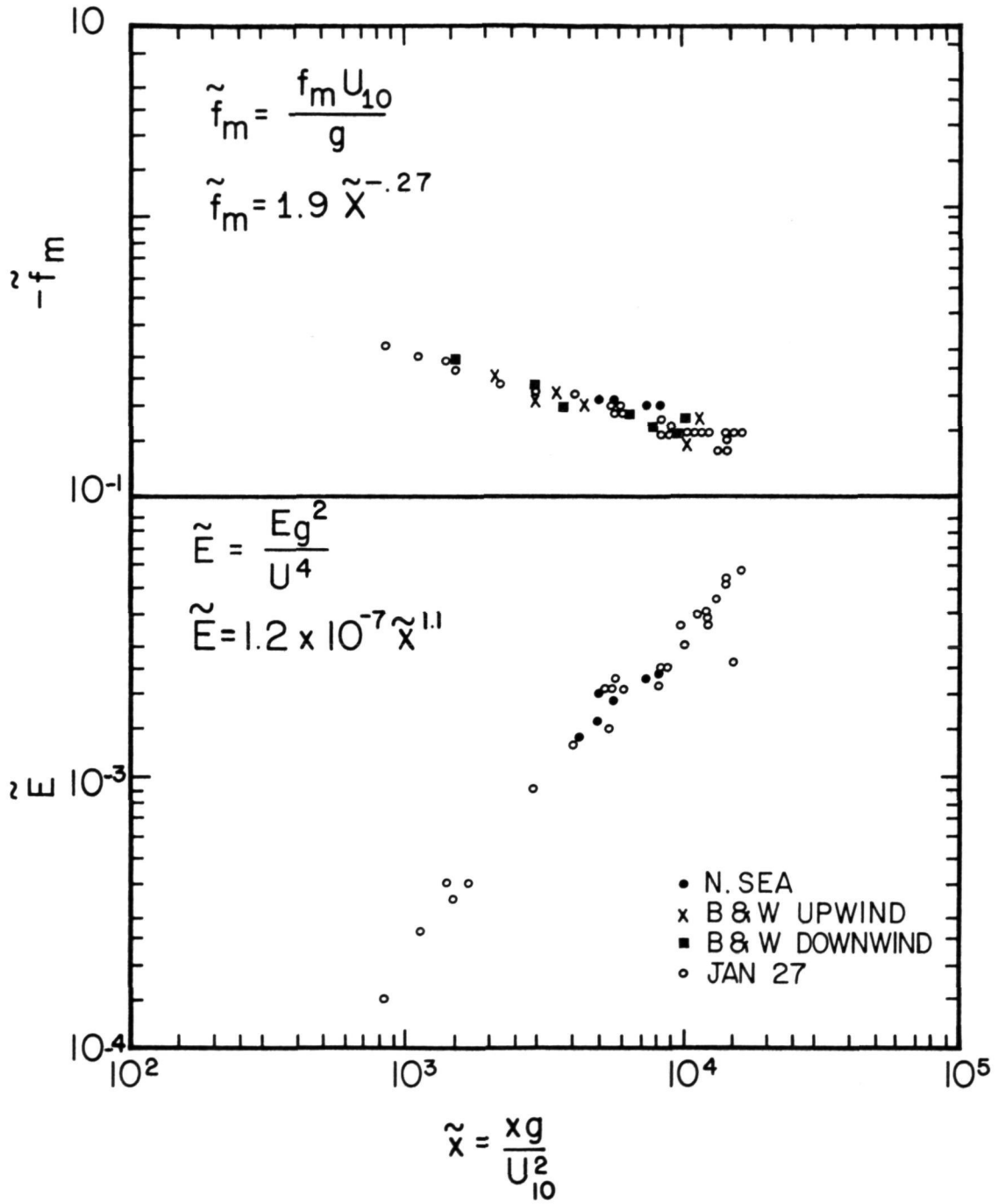


Figure 3. Dimensionless parameters $\tilde{E}$ and $\tilde{f}_m$ versus dimensionless fetch $\tilde{X}$ for high windspeeds (15 to 25 m/sec) as determined by aircraft experiments in the North Sea and off Cape Fear, N. C., on 27 January (Ross and Cardone, 1974, and Barnett and Wilkerson, 1969).

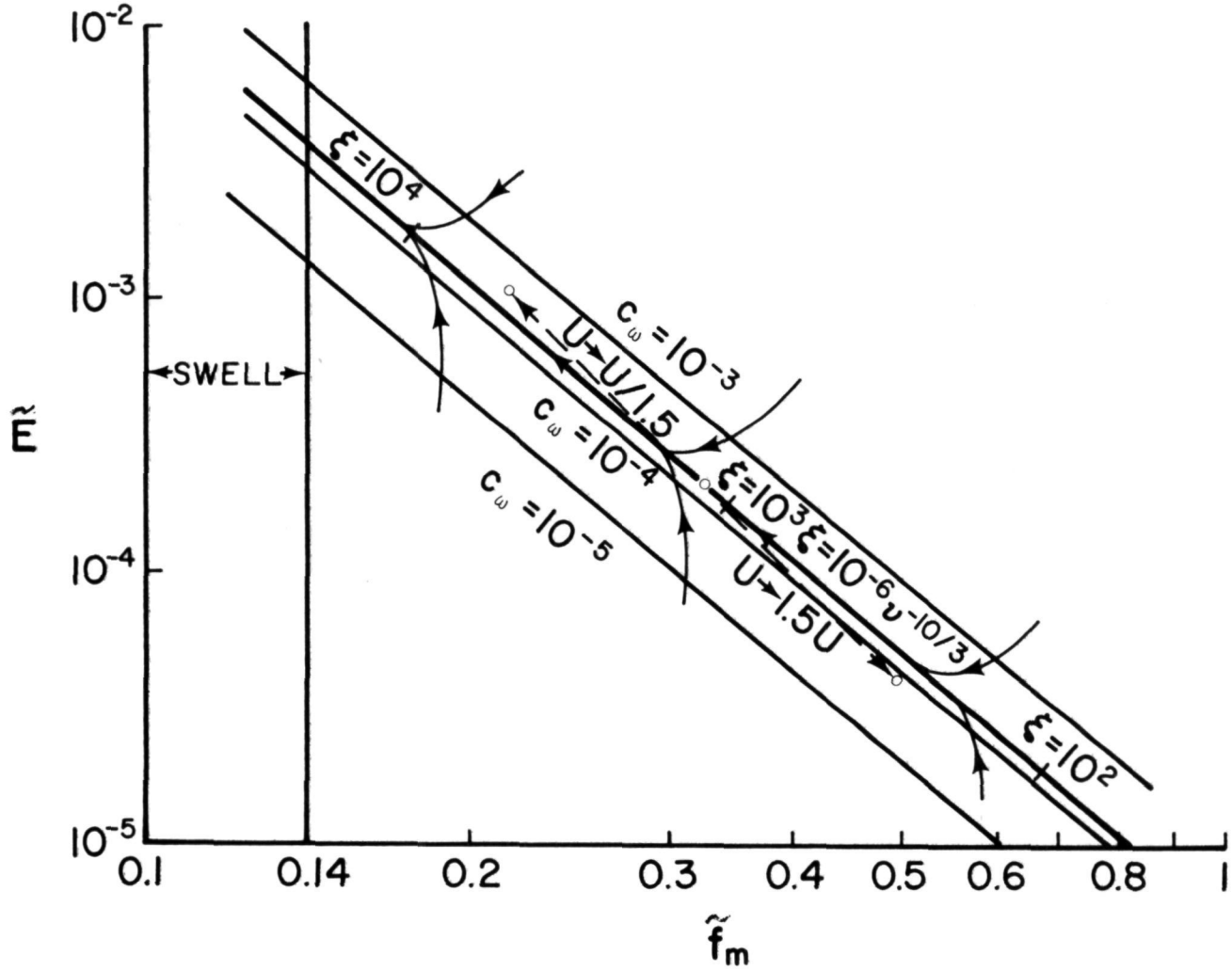


Figure 4. The behavior of $\tilde{E}$ and $\tilde{f}_m$ during growth. A sudden change of windspeed by a factor of 1.5 results in a departure from the mean followed by readjustment to mean condition along the curved lines indicated. Nondimensional fetch relationships $\tilde{X} = E = \frac{xg}{U_{10}{}^2}$ for particular $\tilde{f}_m$ are included. The upper and lower boundaries ($C_\omega = 10^{-3}$ and $C_\omega = 10^{-5}$) represent the limits of momentum being transferred to the wave spectrum.

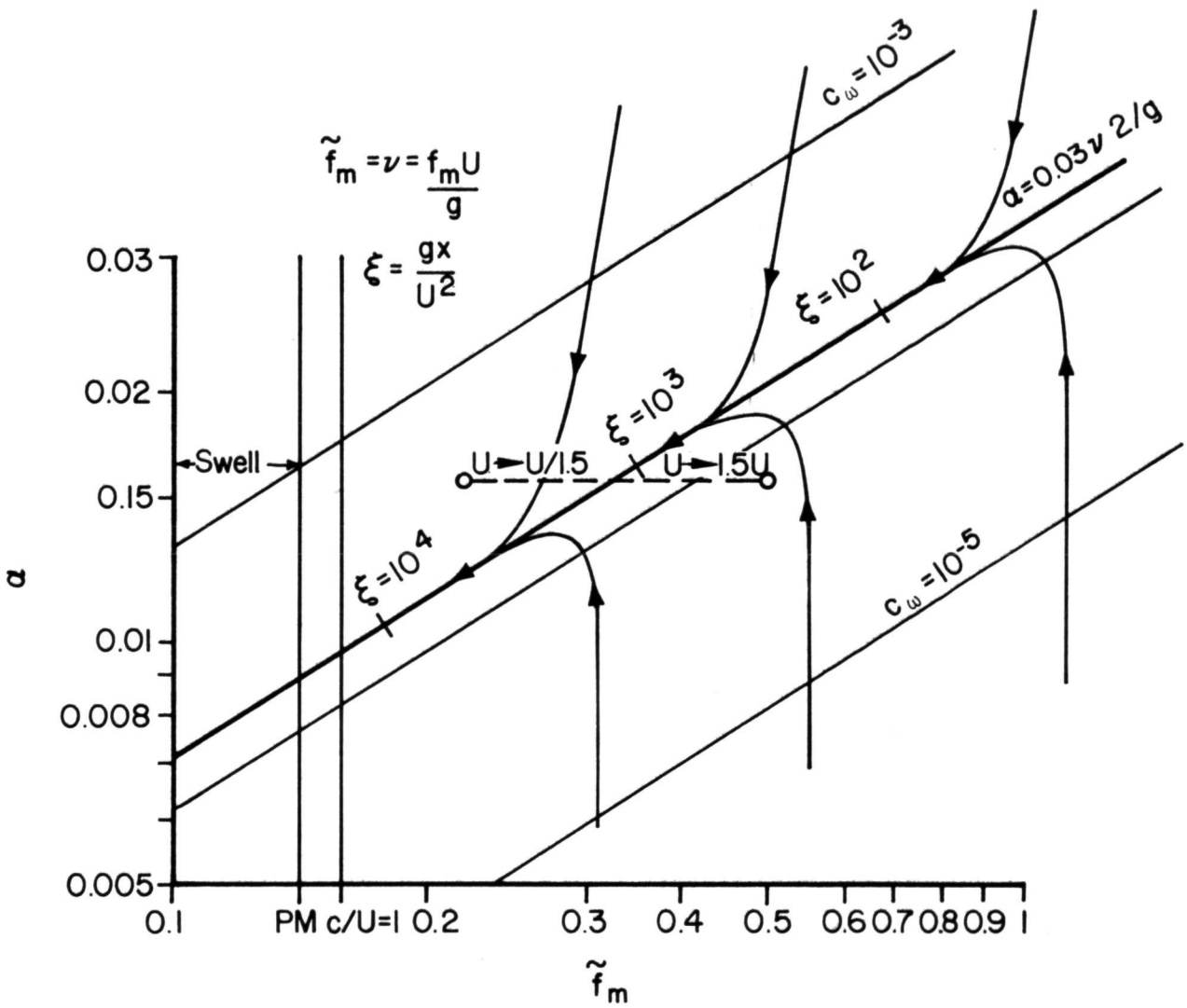


Figure 5. The Phillips parameter α versus $\tilde{f}_m$. Corresponding fetches ξ are indicated by the tick marks. The behavior of α during readjustment to a change in local wind (U) conditions is along the curved lines.

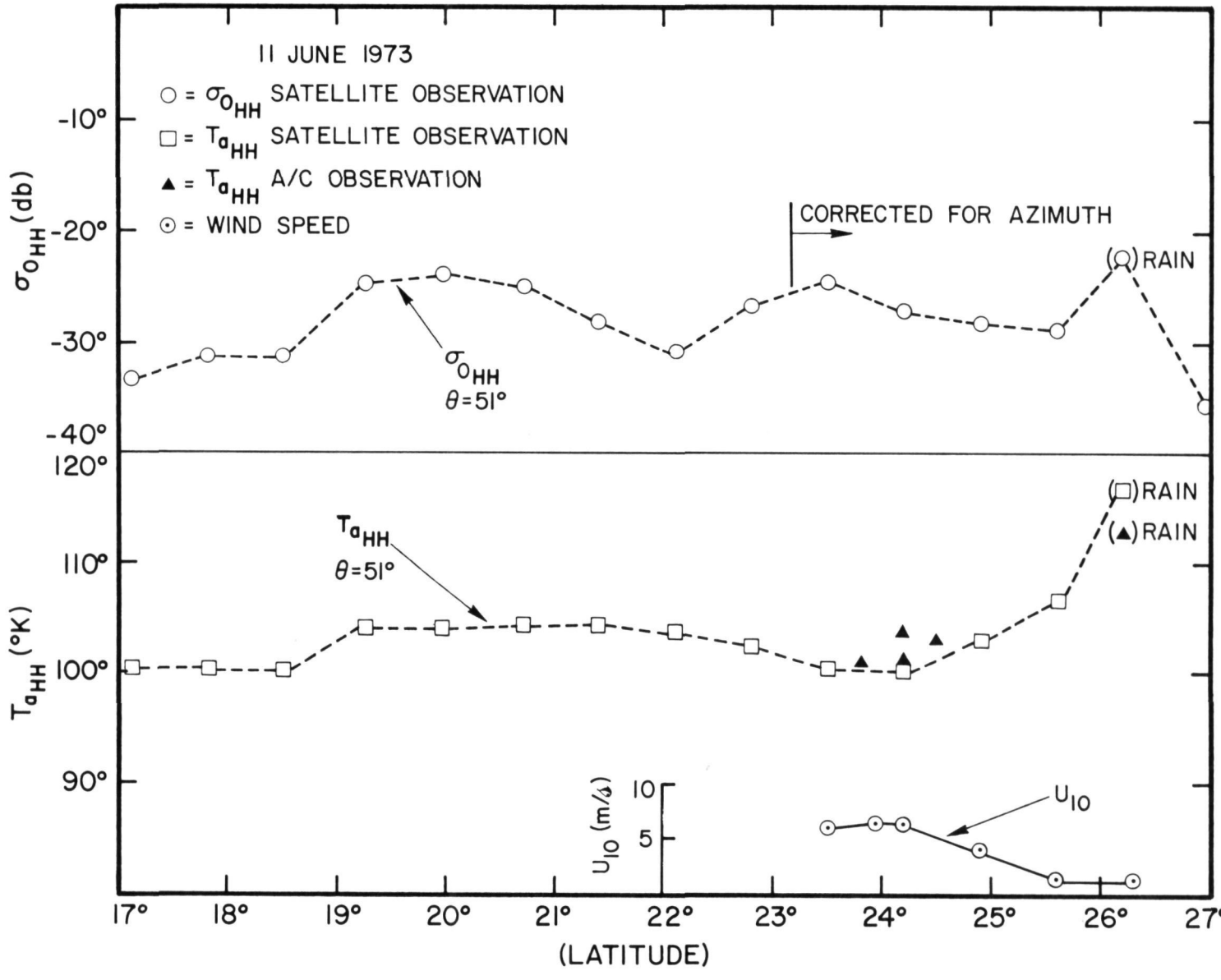


Figure 6. Skylab pass of 11 June in the Gulf of Mexico.

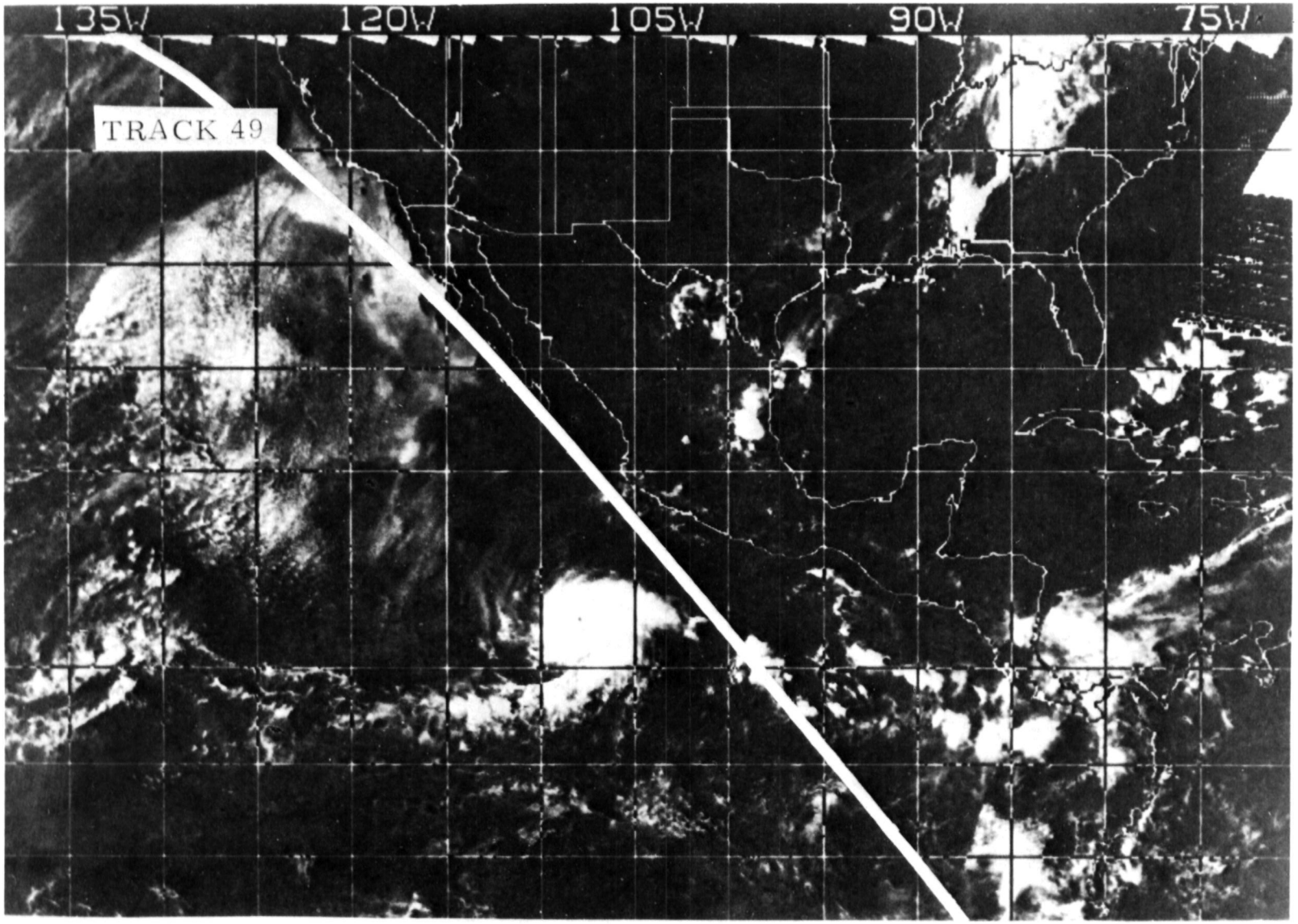


Figure 7. Hurricane Ava, June 6, 1973, NOAA-2 composite showing track of Skylab satellite.

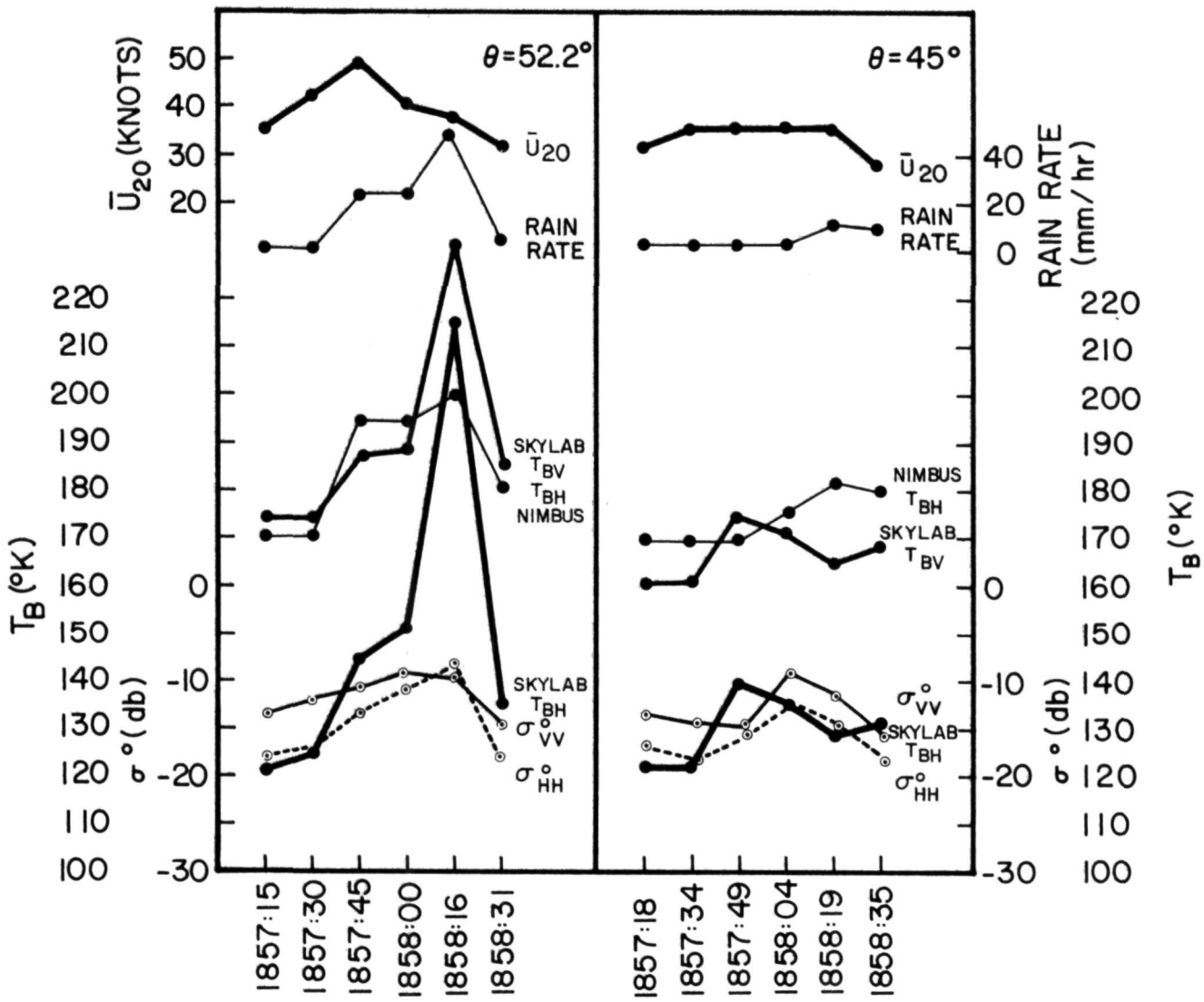


Figure 8. Skylab and NIMBUS-E data in Hurricane Ava.

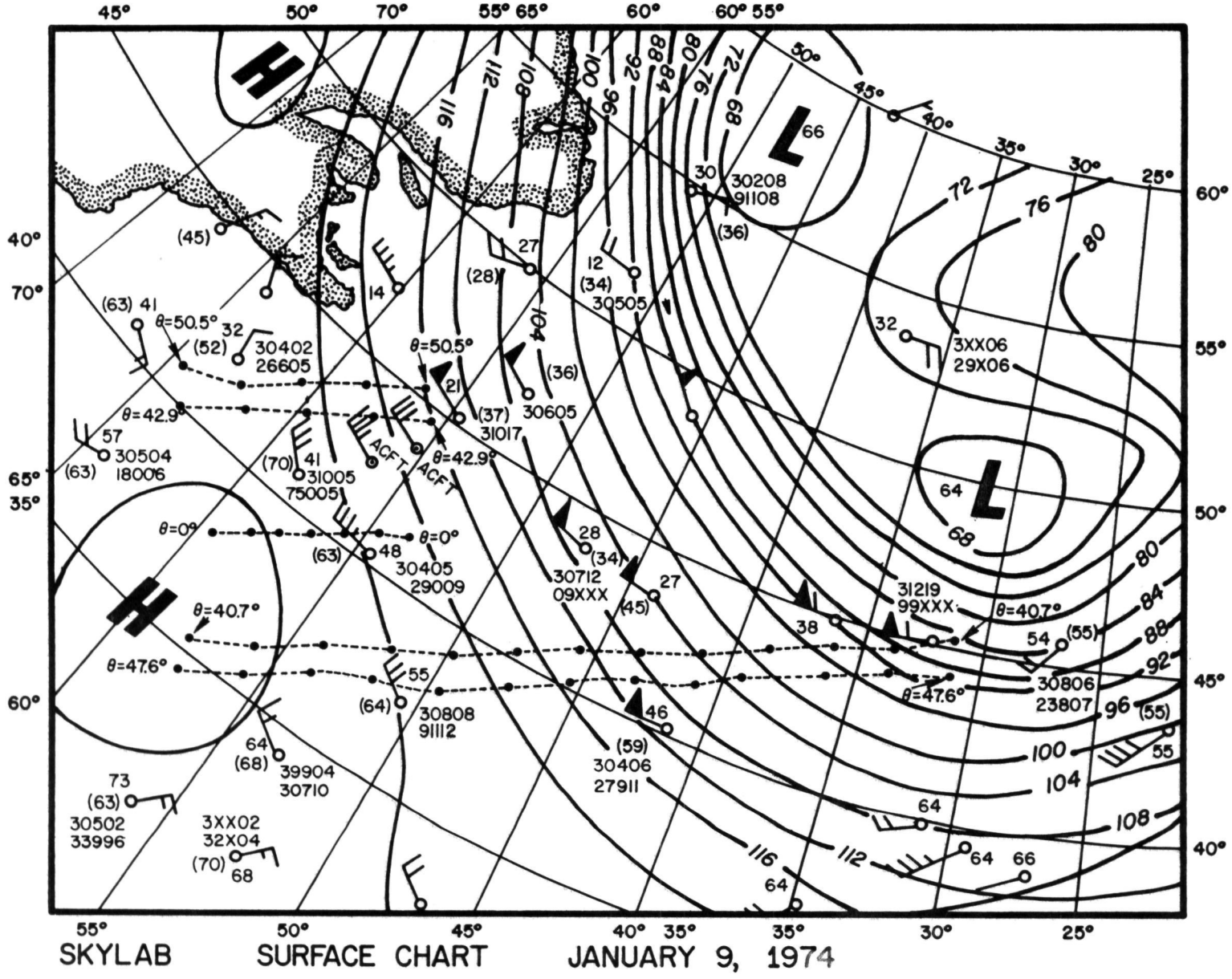


Figure 9. Surface meteorological analysis for 9 January 1974 pass. Subsatellite positions of S-193 under study are shown for the indicated incidence angles.

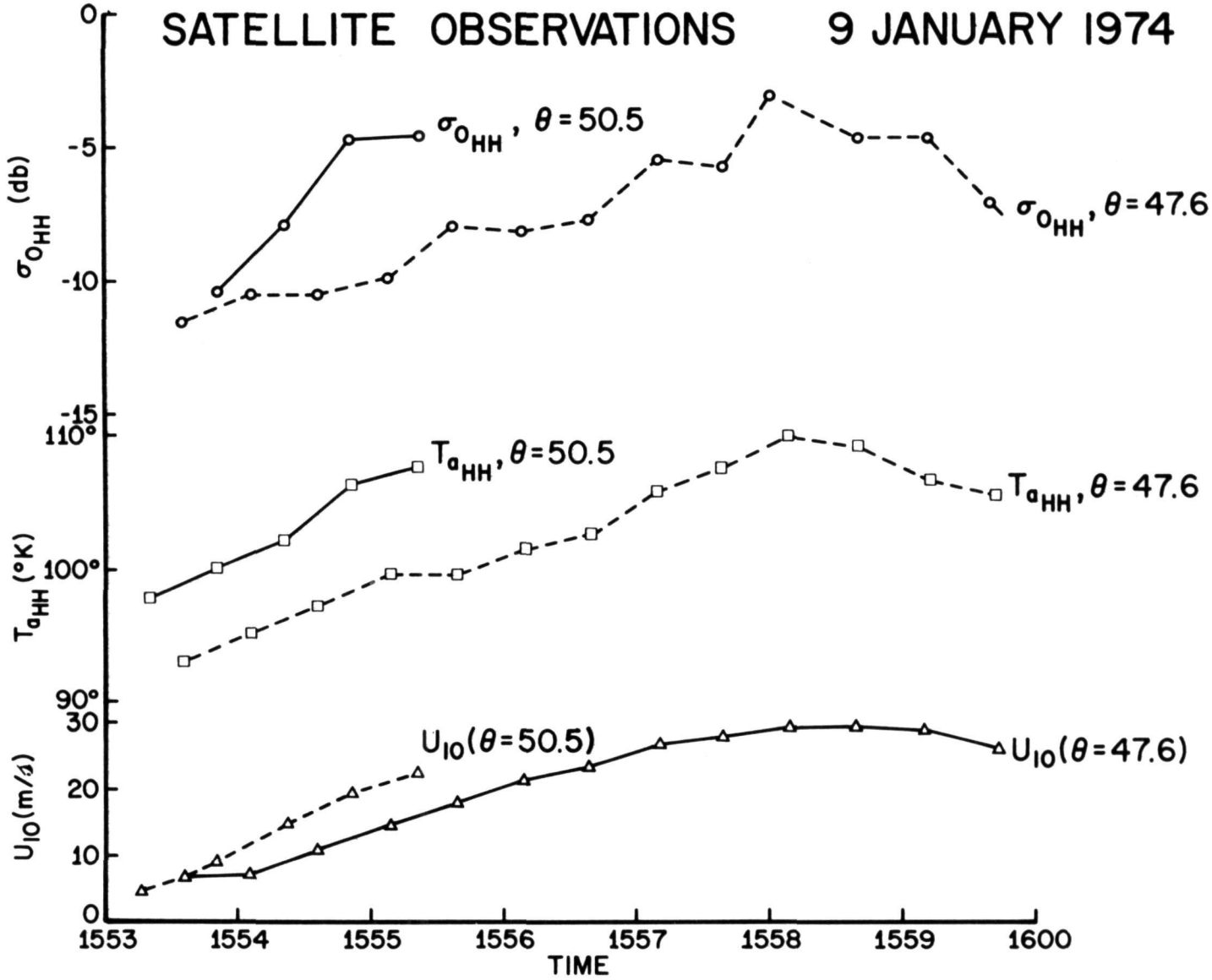


Figure 10. S-193 data during the 9 January pass along with surface winds determined from the surface analysis.

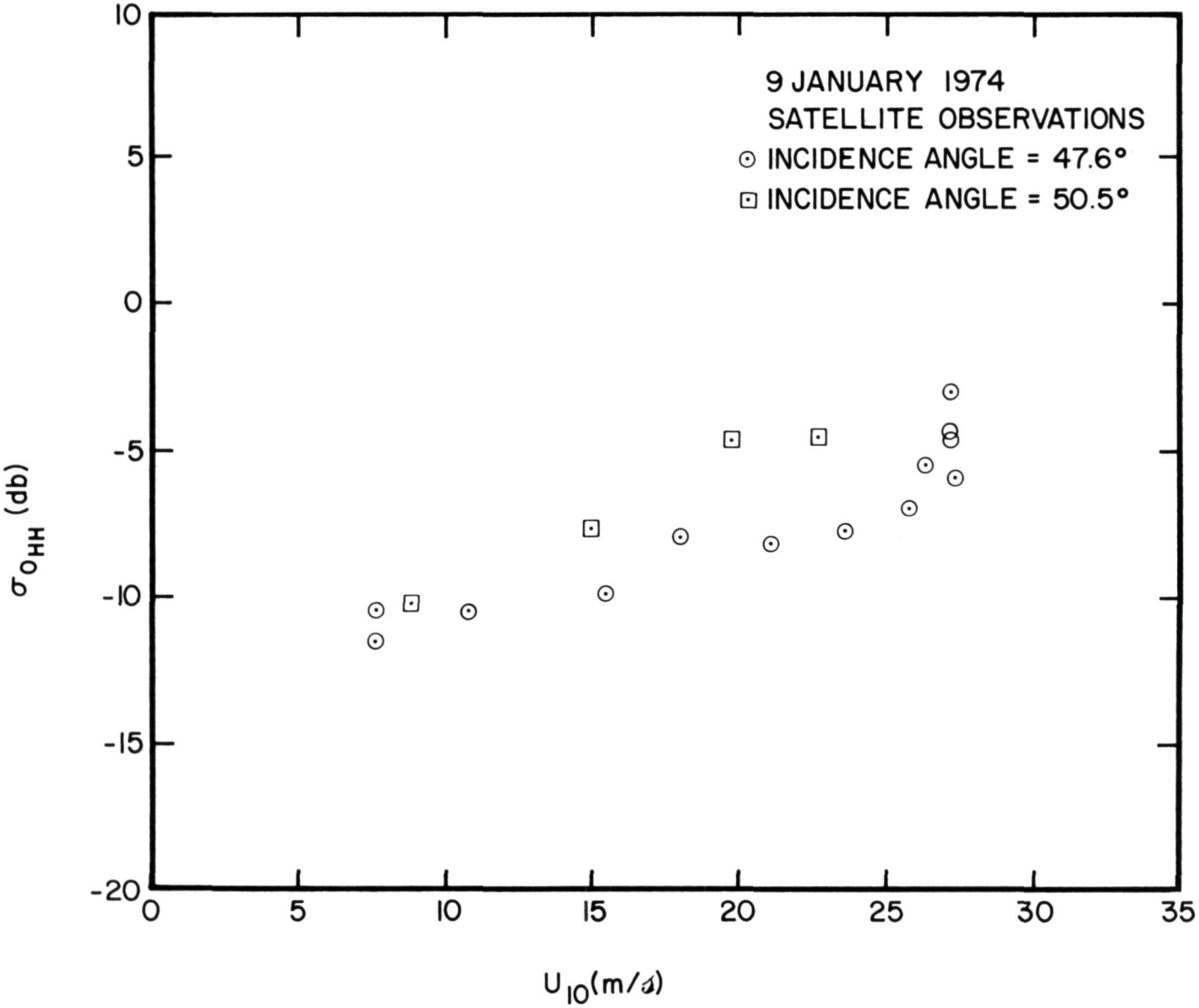


Figure 11. Radar backscatter, σ_0 versus windspeed for 9 January.

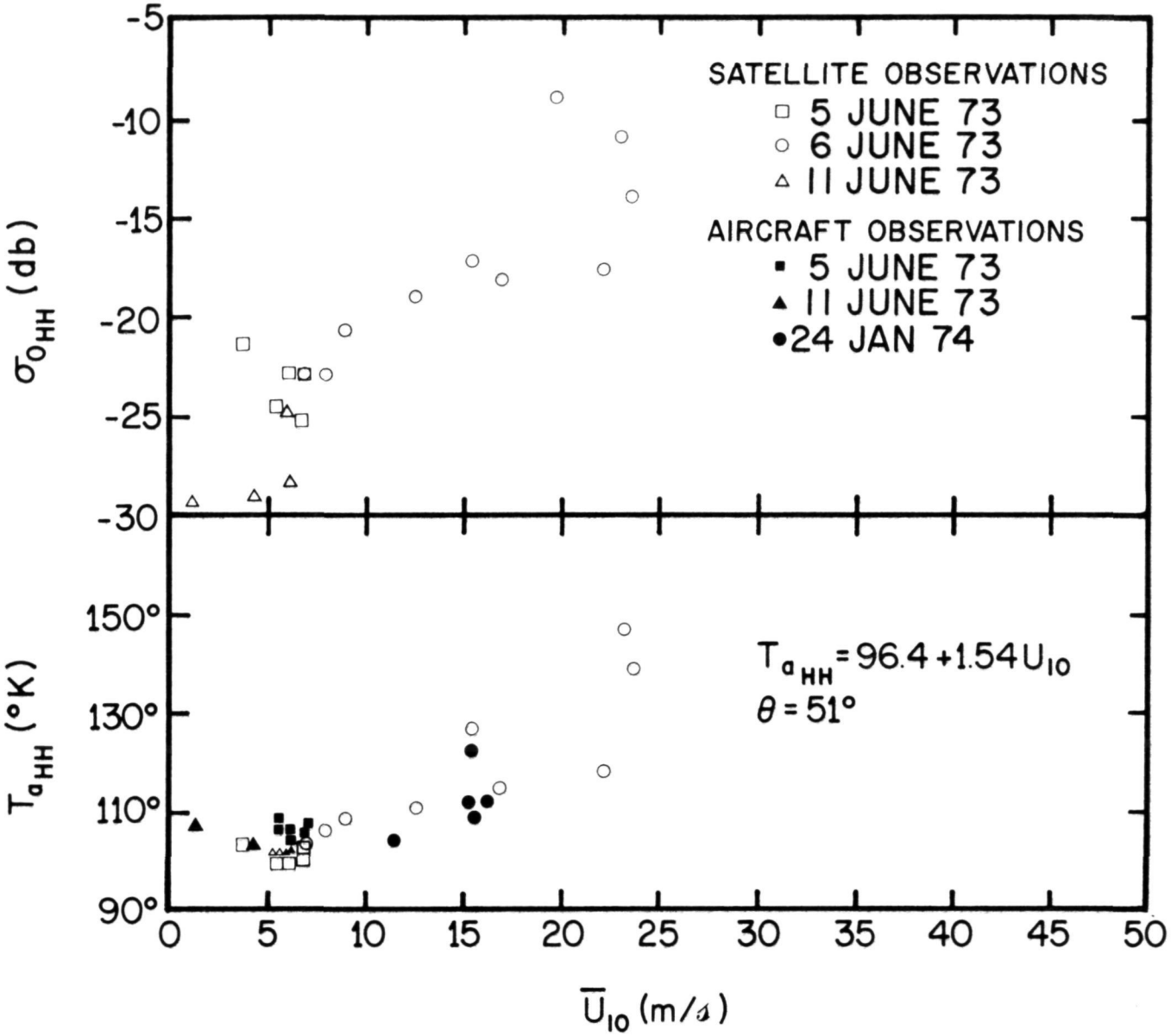


Figure 12. Radar backscatter and antenna temperature versus windspeed during SL-2.

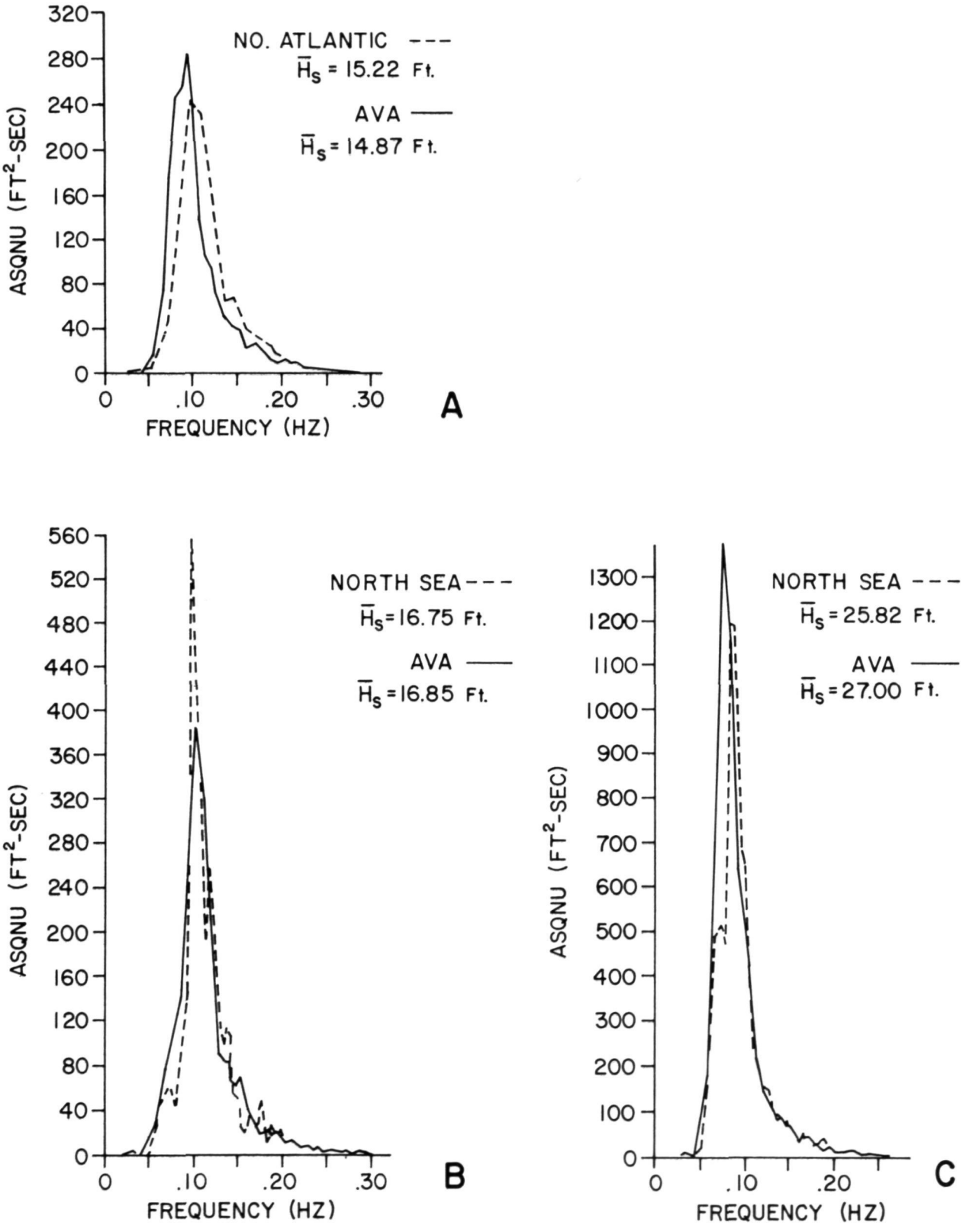


Figure 13. Wave spectra measured during the aircraft penetration of Hurricane Ava along with North Sea spectra for fetch-limited 25 m/sec winds.

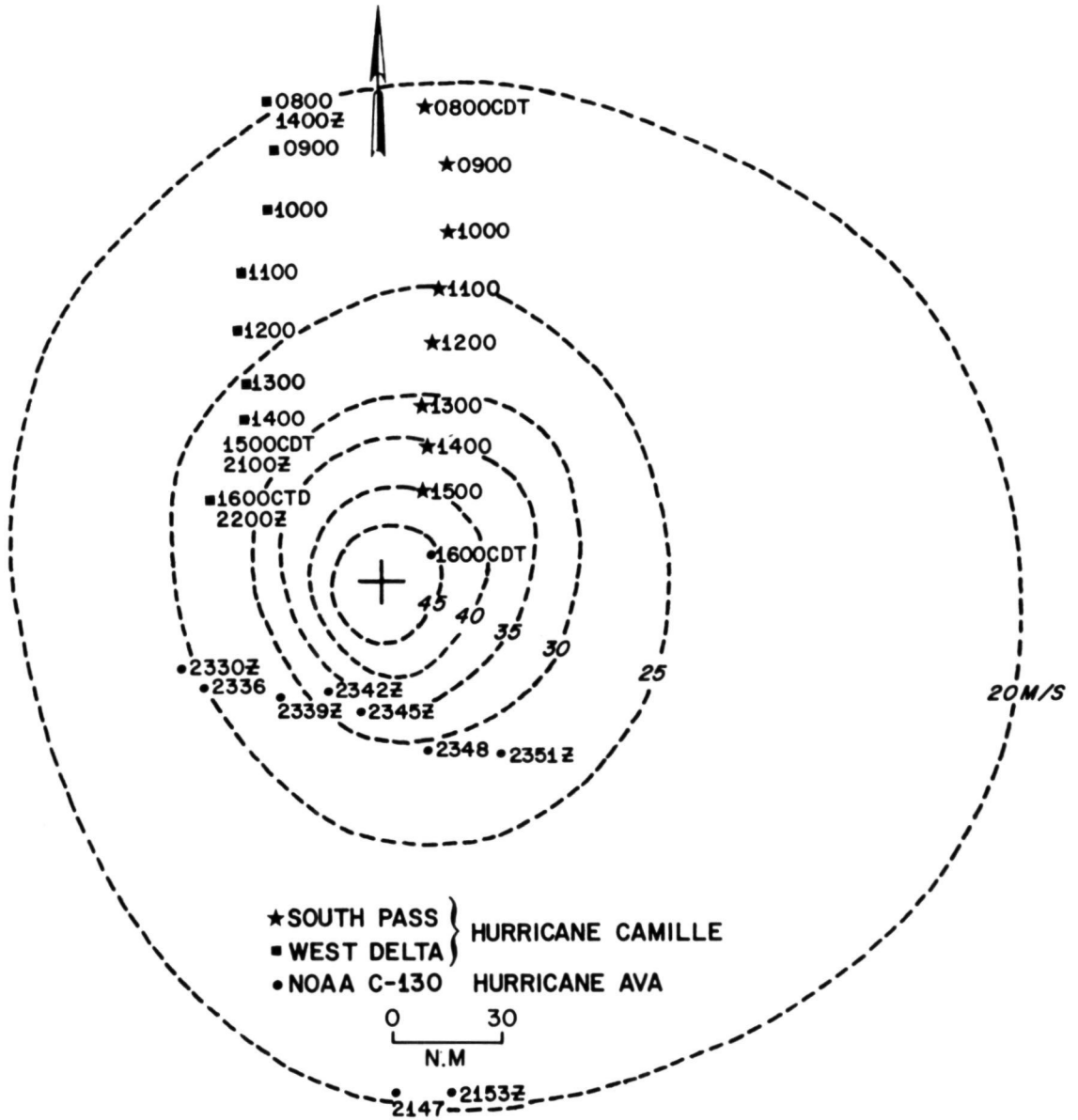


Figure 14. Surface wind analysis for hurricane Ava constructed from aircraft data along with relative positions of wave data obtained in Ava and for Hurricane Camille.

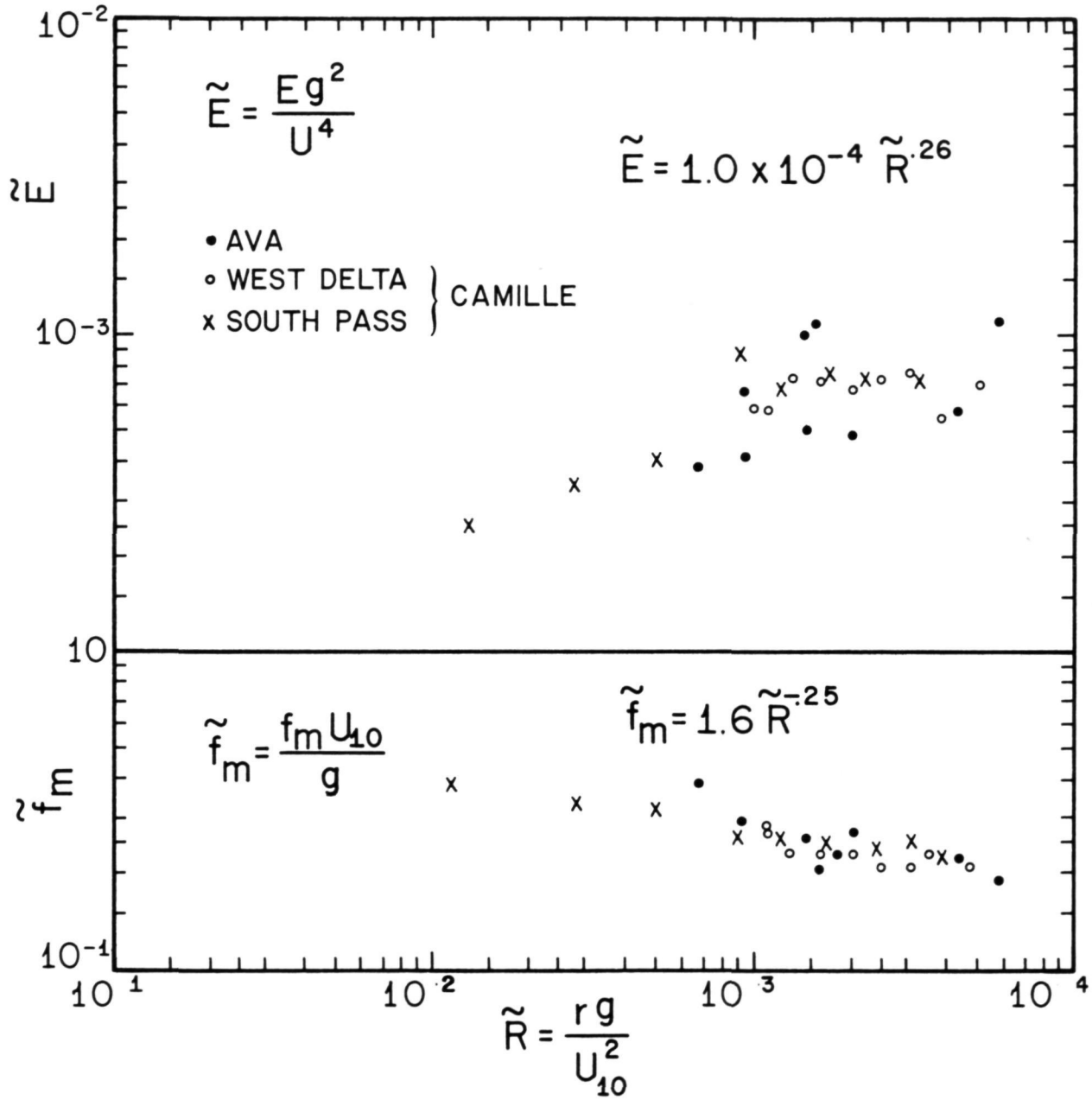


Figure 15. Behavior of nondimensional energy, E, and peak frequency, $\tilde{f}_m$, versus radial distance from eye. $\tilde{R} \approx 10^2$ constitutes the region of maximum winds.

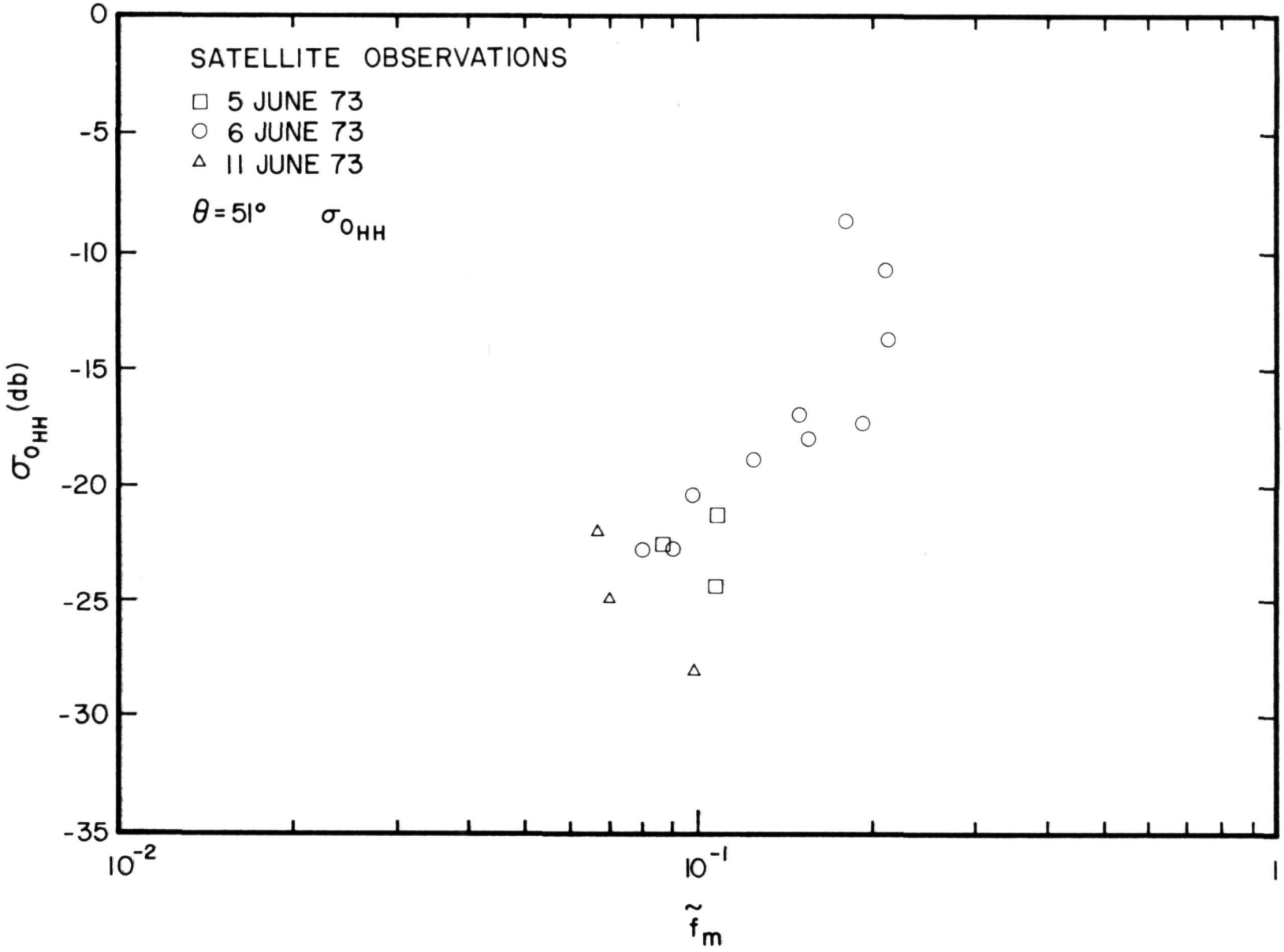


Figure 16. Radar backscatter, σ_0, versus stage of wave development as represented by non-dimensional peak frequency $\tilde{f}_m$ for the SL-2 data set.

SKYLAB S-193 RADSCAT MICROWAVE MEASUREMENTS OF SEA SURFACE WINDS M-3

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ABSTRACT

The small-scale roughness of the sea surface is known to be in equilibrium with the local winds near the surface. Because radar backscatter and microwave emissions are sensitive to surface roughness, they are highly correlated with sea surface winds. The radiometric measurements are more sensitive than the backscatter measurements to variations in the atmosphere. The simultaneous collection of the two measurements permits most atmospheric effects to be removed from the data.

The S-193 Radscat made extensive measurements of many sea conditions. The equivalent 20 meter-elevation wind speeds range from calm to over 30 meters/sec. Measurements were taken in a tropical hurricane (Ava), a tropical storm (Christine), and in portions of extratropical cyclones. Approximately 200 scans of ocean data at 105 kilometer spacings were taken during the first two Skylab missions and another 200 during the final mission when the characteristics of the measurements changed due to damage of the antenna. More than 300 scans at 15 kilometer spacings show the finer spatial variation of winds. Backscatter with four transmit/receive polarization combinations (HH, VV, VH, HV) and emissions with horizontal and vertical receive polarizations were measured.

To correlate the Radscat measurements with surface winds, wind estimates (surface truth) were determined at each cell by objective numerical analysis techniques. These meteorological wind estimates are being analyzed to produce quantitative estimates of their accuracy. This analysis is necessary to relate the performance of microwave surface-truth wind estimator to the performance of a microwave true wind estimator. Results are not available at the time of writing.

Other surface parameters investigated for correlation with the measurements included sea temperature, air/sea temperature difference, and gravity-wave spectrum. The gravity-wave spectrum was estimated from numerical wave specification theories.

Methods were developed to correct the microwave measurements for atmospheric effects. The radiometric data were corrected accurately for clear sky and light cloud conditions only. The radiometer measurements were used to recover the surface scattering characteristics for all atmospheric conditions excluding rain. The radiometer measurements also detected the presence of rain which signaled when the scattering measurement should not be used for surface wind estimation. The ability of the system to operate successfully through clouds is important because clouds cover so much of the oceans.

Regression analysis was used to determine empirically the relation between surface parameters and the microwave measurements, after correction for atmospheric effects. Results indicate a relationship approaching square-law at 50° between differential scattering coefficient and wind speed with horizontally polarized scattering data showing slightly more sensitivity to wind speed than vertically polarized data. These results agree well with theory and show that sea surface winds can be measured accurately from space.

INTRODUCTION

Monitoring of meteorological conditions at sea has important applications which include global weather and wave forecasting, ocean circulation estimation, and severe weather tracking. Knowledge of sea-surface winds can be a valuable part of such a data system, particularly due to the close relation between pressure gradients and wind, and because surface winds are the inputs to wave forecasting programs.

An orbiting system which measures microwave backscatter and emissions from the sea can be used to map sea surface winds. Small-scale surface roughness increases with surface wind speed, and the microwave measurements are sensitive to this change in roughness.

Preliminary results of the analysis of S-193 Radscat microwave measurements over the sea are given here. The research is part of an effort to develop a system to measure sea-surface winds from space on a global basis.

BACKGROUND

Some of the more recent aircraft experimental measurements of backscatter as a function of wind speed are shown in Figures 1 a, b, and c. All of these observations were made near the incident angle range and frequency of the S-193 Radscat. Each shows a nearly linear relation between scattering coefficient in dB and the log of windspeed. A linear relationship between these is equivalent to having $\sigma^o = KW^\alpha$ where σ^o is scattering coefficient and W is wind speed. The exponents, α, estimated from the NASA/JSC, NRL, and AAFE data range from 1 to 1.5 for incident angles from 25° to 65° and are shown in Figure 2. No clear trend with incident angle is evident from these data and the one-standard-deviation confidence intervals for the NRL data are rather large.

Figure 3 shows some experimental measurements of brightness temperature as a function of wind speed.[2] The data show a linear trend between brightness temperature and wind speed for both 0° and 20° incident angle.

THE S-193 RADSCAT

The S-193 Radscat was a combined 13.9 GHz radiometer/scatterometer which operated aboard Skylab. The antenna beam was approximately circular with a two-way beamwidth of about 1.5^o (scatterometer) and a one-way beamwidth of about 2° (radiometer). The scatterometer measured four polarizations (HH, VV, HV, VH) with both vertical and horizontal receive and transmit while the radiometer measured both vertically and horizontally polarized signals.

The modes designed for use over the sea sampled data at 105 kilometer intervals with incident angles of approximately 50°, 40°, 30°, 15°, and 0°. A scan in these modes consisted of four scattering coefficients and two radiometric measurements at each of the five incident angles. Approximately 200 such scans of ocean data were taken during the first two Skylab missions and an additional 200 during the final mission. Backscatter data from the final mission require special processing to partially compensate for the effects of a damaged antenna feed. The radiometric measurements during the final mission are believed to be of little value because of the damage. The results presented here are based on the preliminary analysis of about 25% of the scans obtained during the first two Skylab missions. The analysis of the remainder of data from these missions awaits processing to determine surface truth. Preliminary evaluation of backscatter data from the final Skylab mission indicates that the wind sensitivity of the data was not destroyed by the antenna damage, but these data must still be corrected for the effects of the antenna damage.

The S-193 Radscat also operated in a mode which observed a contiguous two-dimensional array of cells on the surface. The nominal distance between centers of these cells was 13.5 km. Data obtained in this mode can be used to form maps which show the finer spatial variations in the surface winds.

THE AAFE RADSCAT UNDERFLIGHTS

The Advanced Application Flight Experiment program, AAFE, included an aircraft-mounted Radscat capable of measurements similar to those of the S-193 Radscat. This instrument had been operated before the launching of Skylab to measure the wind dependence of backscatter and brightness temperature, but only a limited number of wind speeds were observed by the system (see Figure 1c).

Several AAFE Radscat flights were flown concurrently with the S-193 Radscat operation to compare measurements of the two instruments. The AAFE measurements also give an indication of the fine spatial variations of the return because the area illuminated by the AAFE antenna pattern is much smaller and the measurements are separated by a shorter distance than those of the S-193.

The most important measurements by the AAFE instrument were obtained when the aircraft on which the instrument was mounted flew in a tight circle, an experiment mode designed by W. L. Jones of NASA/LRC. During this maneuver, the AAFE Radscat takes measurements at about 30° incident angle with the azimuthal direction changing continuously. The averaged values of backscatter for four continuous circles are shown in Figure 4. The highest scattering coefficients were measured when the instrument

was pointing upwind, in the direction from which the wind was blowing. A secondary maximum occurs for downwind with minima near crosswind. Some of the scatter in the data is caused from both temporal and spatial variations in the wind field. The solid curve indicates the fit of the first four terms of a Fourier series. Perhaps additional terms need to be added to the model to better fit the minima.

The difference between upwind and crosswind for the 3 m/sec wind speed data shown is about 2.5 dB with about 1 dB difference between upwind and downwind. Data taken for 12 m/sec winds and 40° incident angle indicate about a 6 dB difference in vertically-polarized scattering coefficient between upwind and crosswind. A higher wind speed case has recently been measured, but the processing of these data is not completed.

These data give an indication of the sensitivity of backscatter measurements to wind direction, but data are available for only a few wind speed/incident angle/wave spectra combinations. Furthermore, no data are available to document the effects of wind direction on cross-polarized measurements. To fill in these gaps, we must presently rely on theory. A theory has been developed to explain and extend these results, but results are not given here because estimates of wave slopes used in the theory are being revised.

PRELIMINARY ANALYSIS OF S-193 RADSCAT DATA

The S-193 Radscat measured microwave responses through tropical hurricane Ava and tropical storm Christine. These were the first measurements of ocean backscatter during such storms. The instrument was scanning to one side of the track during both storms and during Christine the instrument measured cells in all four quadrants of the storm. Measurements during Ava have been reported previously.[4,5]

Figure 5 shows the passive and active microwave response as the spacecraft passed by Christine. The figure also shows the wind profile calculated from a meteorological model[6] that uses as inputs central pressure, radius to maximum wind, ambient pressure, and direction and speed of movement of the eye. Unfortunately, the aircraft reconnaissance flights closest to the time of the Skylab pass were 2 hours before and 6 hours after the pass. Both were at an altitude of 3000 meters. For these reasons, the location of the eye at the time of the Skylab pass is uncertain. Even so, Figure 5 shows good correlation between backscatter and windspeed. The surface truth wind speed peaks at scan 10 while the scattering coefficients remain high from scan 10 through scan 12 or 13. This could be the result of the wind peak not being as sharp as indicated by the wind models. Secondary peaks in wind speed often occur in such storms.

The high apparent temperature at scan 13 indicates the presence of heavy rain. In such cases, the scatterometer receives substantial backscatter from the rain drops and should, therefore, not be used to estimate surface wind speed.

Several data segments over the sea were observed by the S-193 in a mapping mode. Figure 6 shows the backscatter and apparent temperatures which were measured southeast of Vietnam. Twelve measurements were taken in the cross-track dimension which is the narrow dimension of the images. The upper four images are of the South China Sea and the lower four are of the Flores Sea (south of Borneo). The left two images of each sea show different ranges of scattering coefficients and the right two show apparent temperature. Thresholds for the printing were set differently for a than for b, and for c than for d.

The left-most image of each sea, a, identifies the land-sea boundaries from the backscatter. The c apparent temperature images can next be used to identify the location of rain. Note the two rain bands about 160 and 260 kilometers north of and parallel to the Borneo coast. Additional rain patches are near Vietnam. The high apparent temperatures over the sea indicated in images d show the areas of thick cloud cover. A front appears to be present north of Borneo. The winds may be inferred from the backscatter from ocean areas not experiencing rain. The wind sensitive measurements may be seen in images b. The backscatter north of the front is 4 to 6 dB higher than that south of the front. This difference could be due to a change in wind speed, but much of the difference is probably due to a change in direction which is usually associated with such fronts. The winds along the northern coast of Borneo are probably cross-wind w.r.t. the instrument and those to the north of the front are more up or down wind. Figure 7 shows the same area with the levels of scattering coefficient and apparent temperatures distinguished by color enhancement. The surface truth for this area is currently being compiled.

The wind speed dependence of the backscatter data at 40° incident angle is indicated in Figures 8, 9, and 10. The points shown in these figures represent about 25 per cent of the data collected during the first two Skylab missions and are those for which preliminary surface truth is available. The data were taken at many different aspect angles relative to wind direction. Because backscatter can vary by as much as 6 dB due to aspect angle differences, an aspect angle correction based on an AAFE circle flight has been applied to the like-polarized data shown in Figures 8 and 9. It should be noted, however, that the scatter of the points in Figures 8 and 9 was not substantially reduced by applying the aspect angle correction. Furthermore, when a linear function of log wind speed was fit to the measured values in dB, the residuals of the fit plotted versus aspect angle did not display any significant trend. These results may be due to inaccurate meteorological wind estimates or simply to the limited size of the data set. For whatever reason, the aspect angle corrections currently applied to these data have questionable validity.

The nearly linear trend between scattering coefficient in dB and log wind speed is clearly evident in each of the three figures. The scatter in the data is greater than one might like; however, much of the scatter is due to uncertainties in the surface truth wind speed. The surface truth values are calculated using pressure and wind measurements from ships and planes in the area. Often there are no sources of the meteorological measurements close in time or space to the Radscat measurements. Even with measurements close to the Radscat cells, the surface truth wind speeds may have an r.m.s. error of 2 m/sec or greater. A quantitative evaluation of the accuracy of the surface truth is underway to identify the portion of scatter in the data due to surface truth errors.

Measurements made with the AAFE Radscat during one of the Gulf of Mexico passes showed very close agreement with both S-193 data and local wind speed measured from the aircraft.[7] These values of wind speed were significantly different from those given by the meteorological analysis used here and based on observations at points far from the Radscat observation cells. This lends considerable credence to the hypothesis that much of the scatter is due to inaccurate knowledge of surface conditions from meteorological analysis. In other words, "surface truth" often is not very "true"!

The preliminary power law trends indicated by the S-193 data analyzed to date are shown in Figure 11. The exponents of wind speed range from close to 1.5 to just over 2 with horizontally polarized data having a slightly larger exponent than vertically polarized for the two highest incident angles. The increase of the exponent with incident angle is clearly indicated while such a trend was not apparent in the data shown in Figure 2. This increase with incident angle was predicted in previous work on the basis of the small-perturbation theory and latest estimates of the capillary part of the wave spectrum.

CONCLUSION

Measurements with the S-193 radiometer/scatterometer have confirmed the strong relationship between scattering coefficient for microwave backscatter and the surface winds on the sea. The sensitivity appears to be somewhat greater than that shown in earlier aircraft measurements, but is in line with the results of AAFE Radscat underflight experiments. Sensitivity is somewhat greater for horizontal than for vertical polarization at the higher angles, with cross-polarized results giving essentially the same sensitivity as horizontally polarized.

During Hurricane Ava and tropical storm Christine, measurements were made in high winds and during the occurrence of heavy rain. The ability of the radiometer to detect the presence of the rain and thereby to warn that the scatterometer results are questionable or should be corrected was demonstrated.

Because of late arriving data, surface truth computations for most Skylab passes have not yet been combined into the analysis, so the results presented here are based on two passes during relatively calm weather and the two large storms. The surface truth data are now available, and at the time of writing were in the process of being combined with the Skylab data. Extensive measurements were made in the North Atlantic during SL-4, and the especially processed data (degraded because of antenna damage) are just becoming available at the time of writing.

Use of the Cross-Track-Contiguous mode of the S-193 permits observation of moderately fine scale variations in the surface wind structure, as well as the rain structure. Although analysis of these data is just commencing, two interesting examples have been presented here to illustrate the type of variation encountered.

REFERENCES

1. Bradley, G.A., "Remote Sensing of Ocean Winds Using a Radar Scatterometer," Ph.D. Thesis, University of Kansas Center for Research, Inc., September, 1971.

2. Moore, R. K., J. P. Claassen, A. K. Fung, S. Wu, and H. L. Chan, "Toward Radscat Measurements Over the Sea and Their Interpretation," in Advanced Applications Flight Experiments Principal Investigators' Review, NASA Langley Research Center, October, 1971, pp. 115-140.

3. Jones, W. L. et al., IEEE Intercon Technical Papers, IEEE International Convention and Exposition, Session 34, Ocean Physics Applications Program, March 26-29, 1974.

4. Cardone, V. J., R. K. Moore, W. J. Pierson, and J. D. Young, "Preliminary Report on Skylab S-193 Radscat Measurements of Hurricane AVA," The University of Kansas Center for Research, Inc., Remote Sensing Laboratory, Technical Report 254-1, October, 1973.

5. Moore, R. K., J. P. Claassen, A. C. Cook, D. L. Fayman, J. C. Holtzman, A. Sobti, W. E. Spencer, F. T. Ulaby, J. D. Young, W. J. Pierson, V. J. Cardone, J. Hayes, W. Spring, R. J. Kern, and N. M. Hatcher, "Simultaneous Active and Passive Microwave Response of the Earth--The Skylab Radscat Experiment," Presented at the 9th International Symposium on Remote Sensing of Environment, Ann Arbor, Michigan, 15 April, 1974.

6. Chow, Shu-Hsien, "A Study of the Wind Field in the Planetary Boundary Layer of a Moving Cyclone," New York University Department of Meteorology and Oceanography, (M.S. Thesis), 1971.

7. Jones, W. L., personal communication.

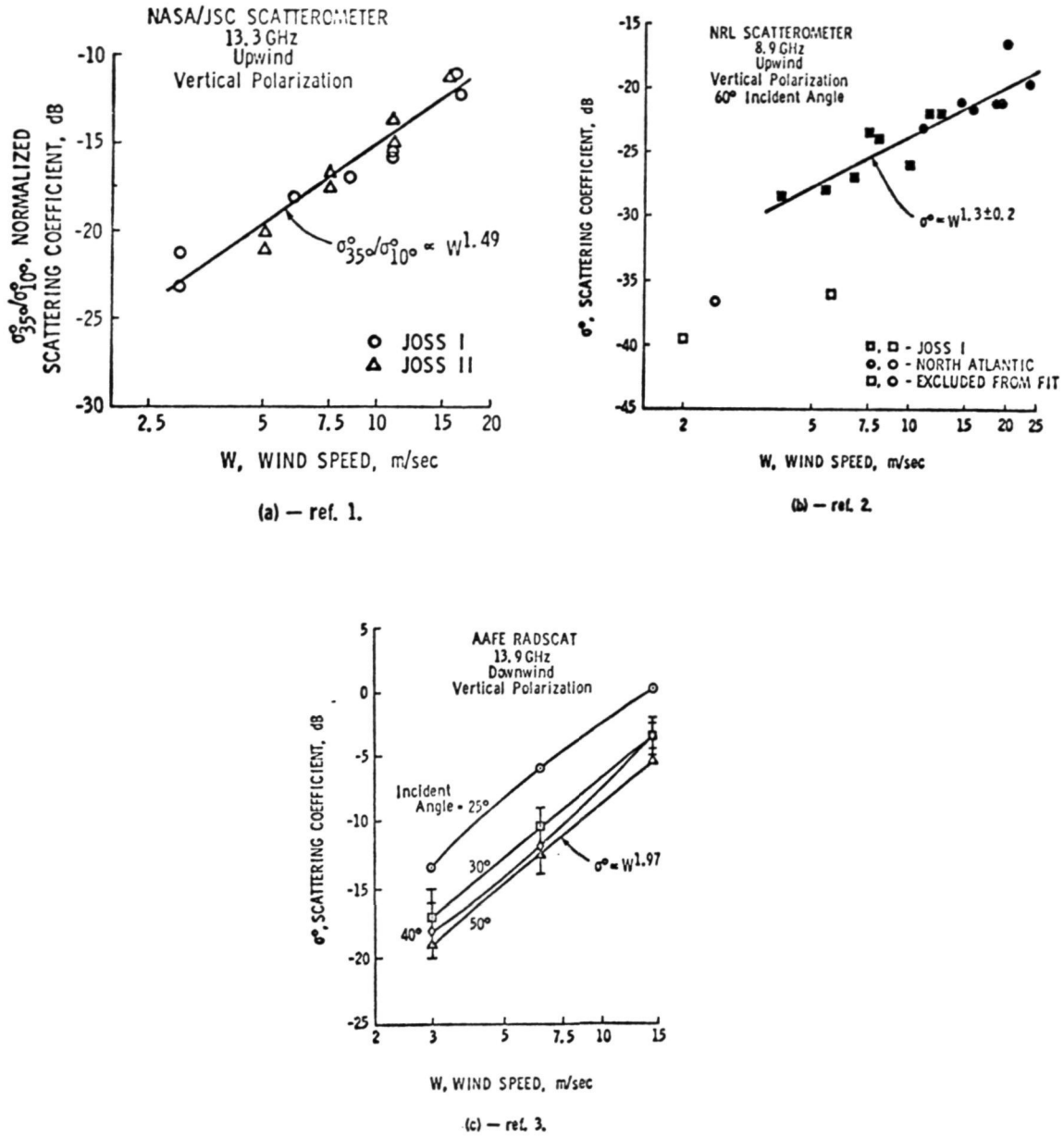
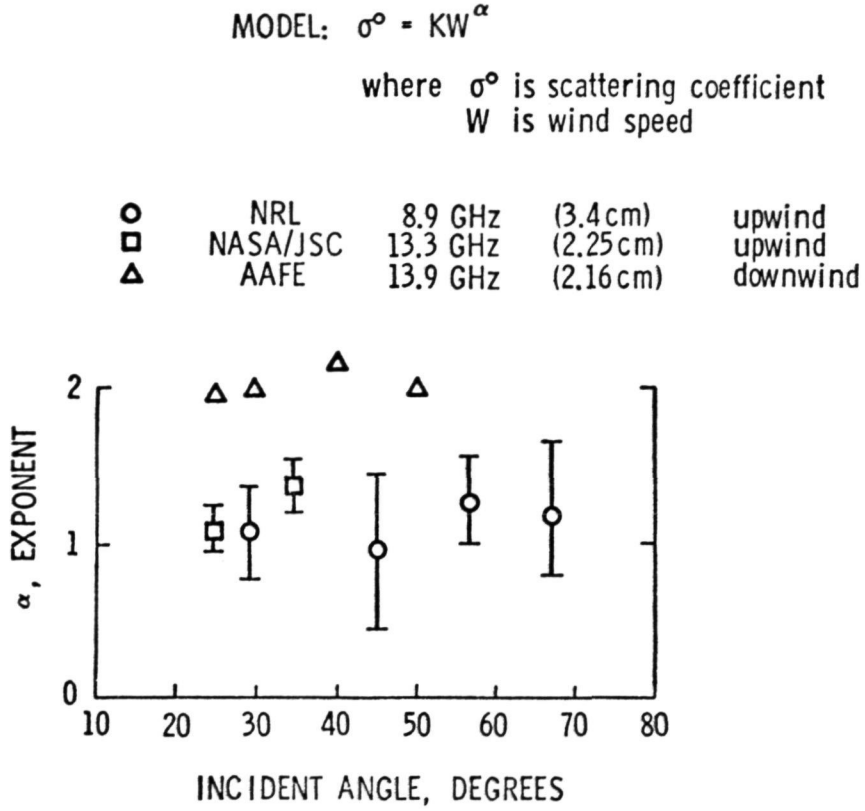


Fig. 1. MEASURED WIND SPEED DEPENDENCE OF SCATTERING COEFFICIENTS



Error bars indicate ± one estimated standard error
(No estimated standard errors are available for the AAFE data)

Fig. 2. EMPIRICAL ESTIMATES OF THE POWER LAW RELATING WIND SPEED AND VERTICALLY POLARIZED SCATTERING COEFFICIENTS

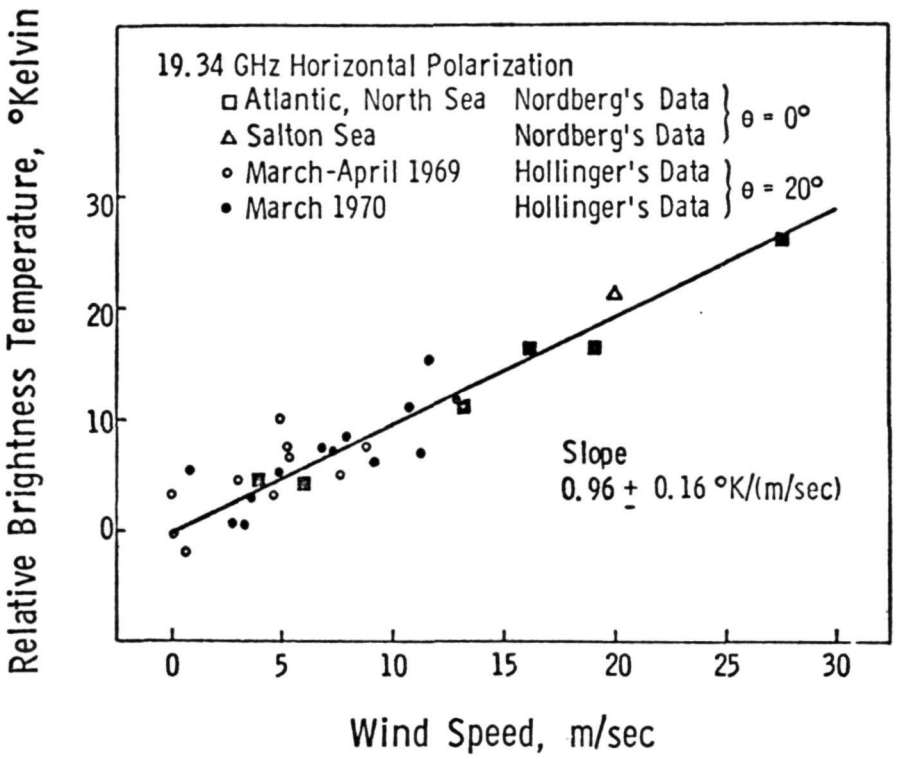


Fig. 3. Correlation between Radiometric Brightness Temperature of the Sea and Surface Wind Speed. Ref. 2.

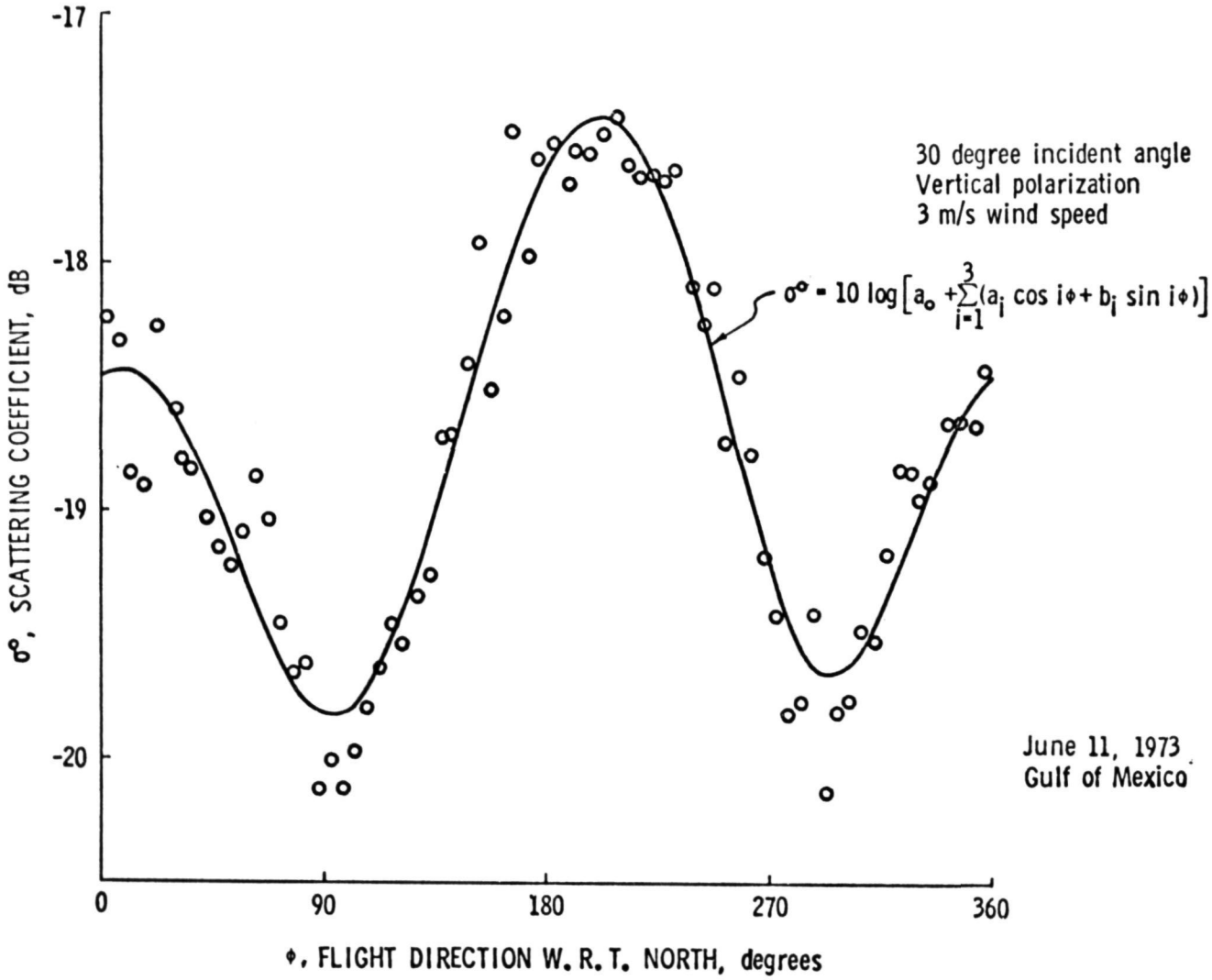


Fig. 4. MEASURED WIND DIRECTION DEPENDENCE OF SCATTERING COEFFICIENTS

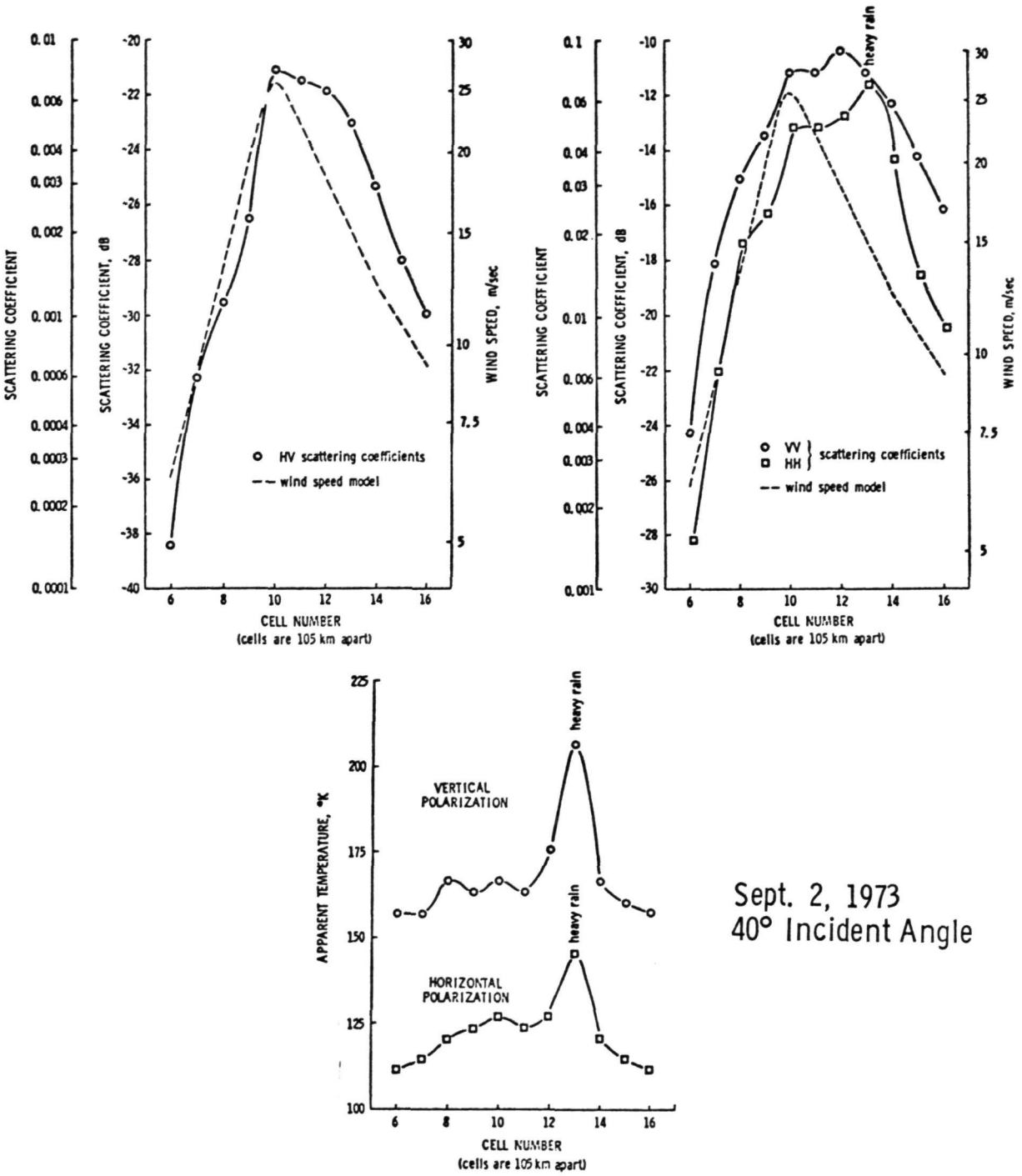
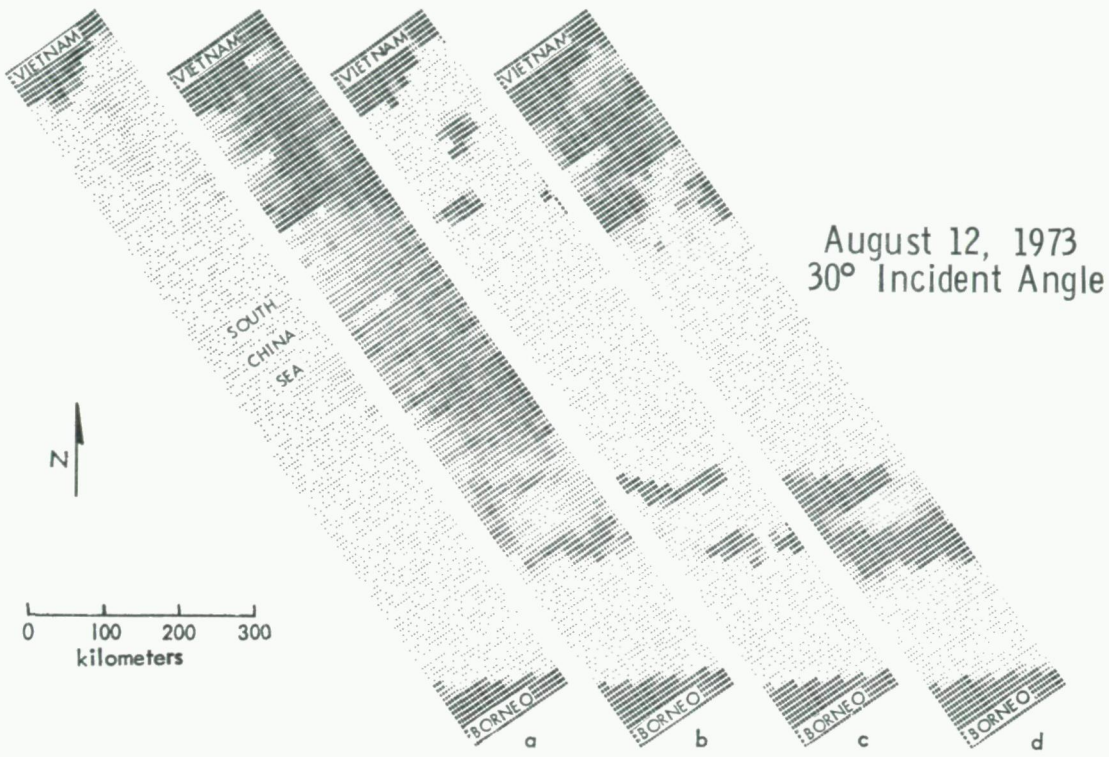


Fig. 5. SCATTERING AND RADIOMETRIC RESPONSES OF TROPICAL STORM CHRISTINE



EXTREMES	a	b	c	d
	σ°_{HH}>-6 dB land	σ°_{HH}>-10 dB land or rain or sea surface winds such as: upwind>9 m/s crosswind>13 m/s	T_H>170°K land or rain	T_H>150°K land or rain or heavy clouds
	σ°_{HH}<-11 dB sea	σ°_{HH}<- 15 dB sea surface winds such as: upwind<6 m/s crosswind<8m/s	T_H <160° K sea	T_H<130°K clear or light clouds over sea

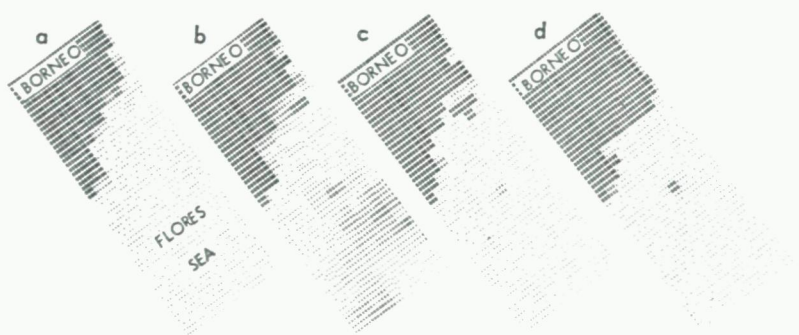


FIG. 6. SCATTERING AND RADIOMETRIC RESPONSES FROM THE SOUTH CHINA AND FLORES SEAS

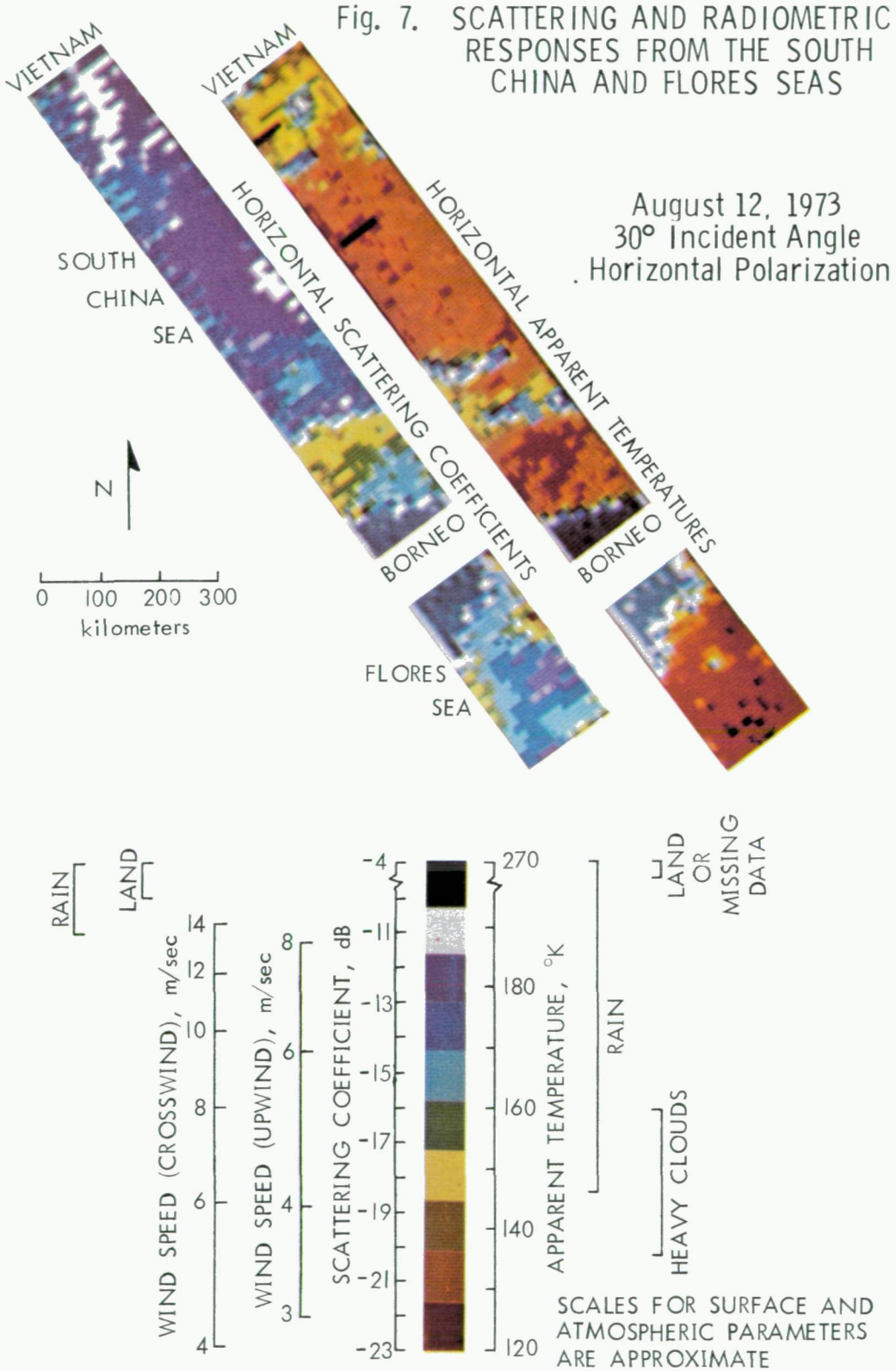


FIG. 7. SCATTERING AND RADIOMETRIC RESPONSES FROM THE SOUTH CHINA AND FLORES SEAS

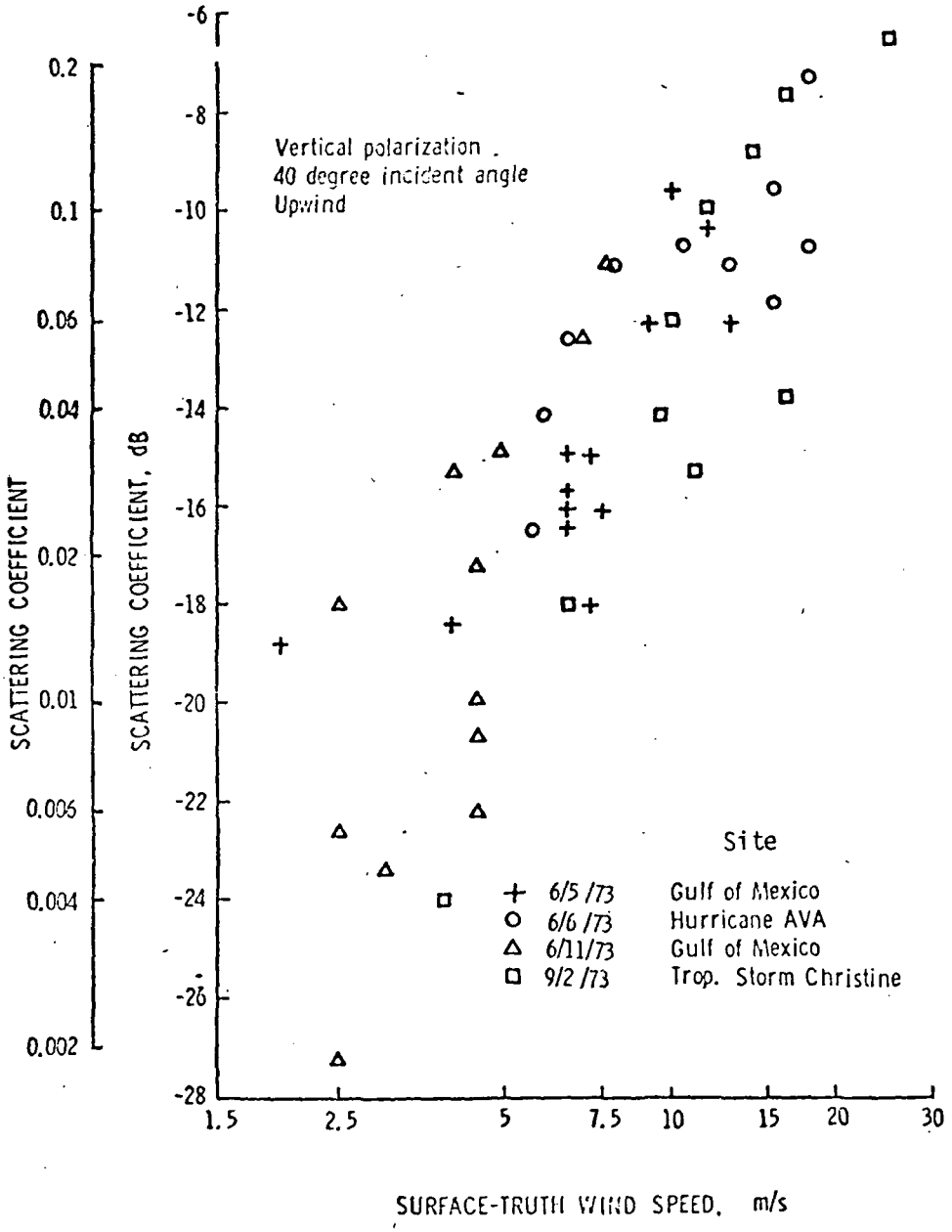


FIG. 8. WIND SPEED DEPENDENCE OF SCATTERING COEFFICIENTS (PRELIMINARY), VERTICAL POLARIZATION

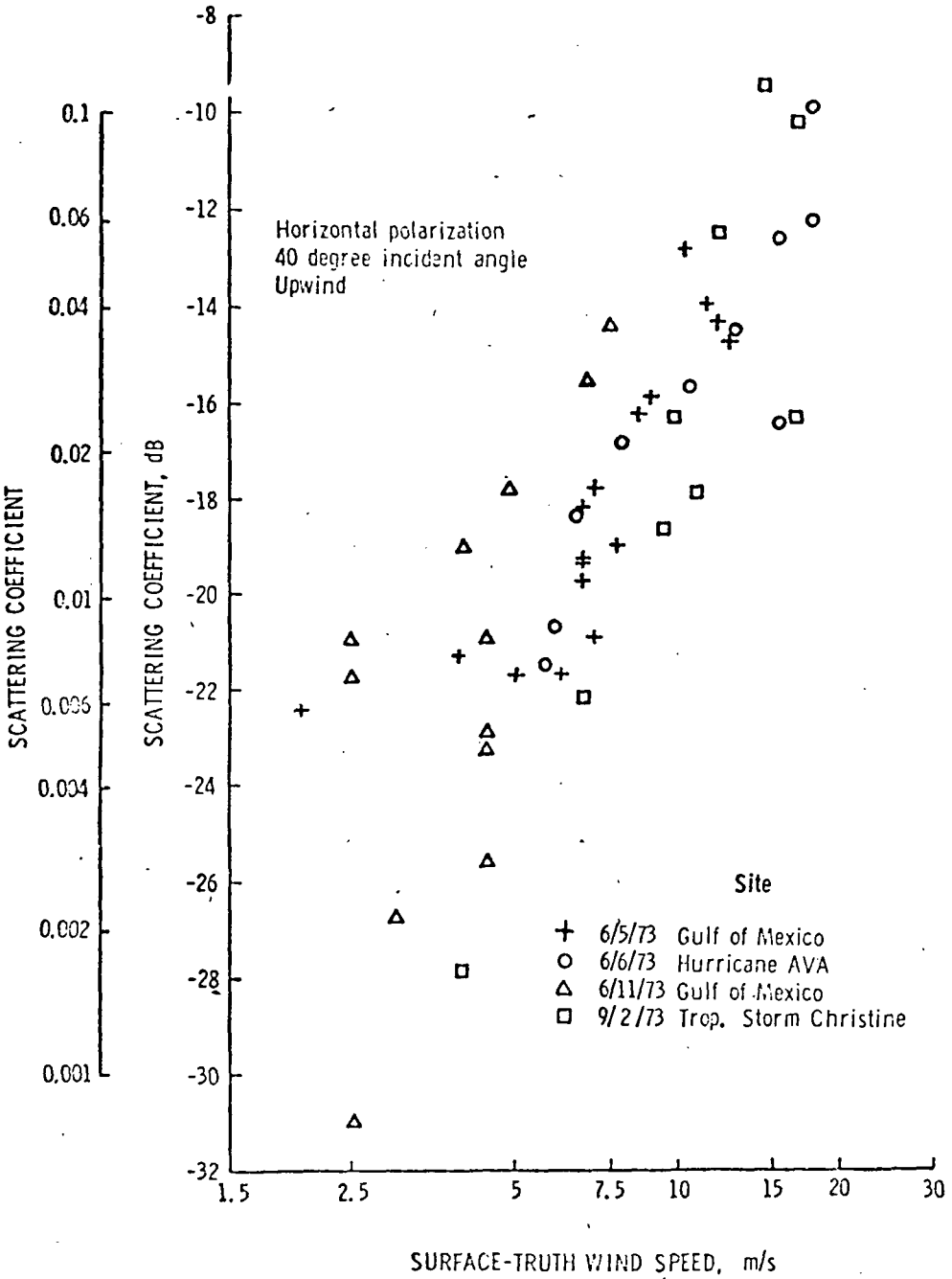


FIG. 9. WIND SPEED DEPENDENCE OF SCATTERING COEFFICIENTS (PRELIMINARY), HORIZONTAL POLARIZATION

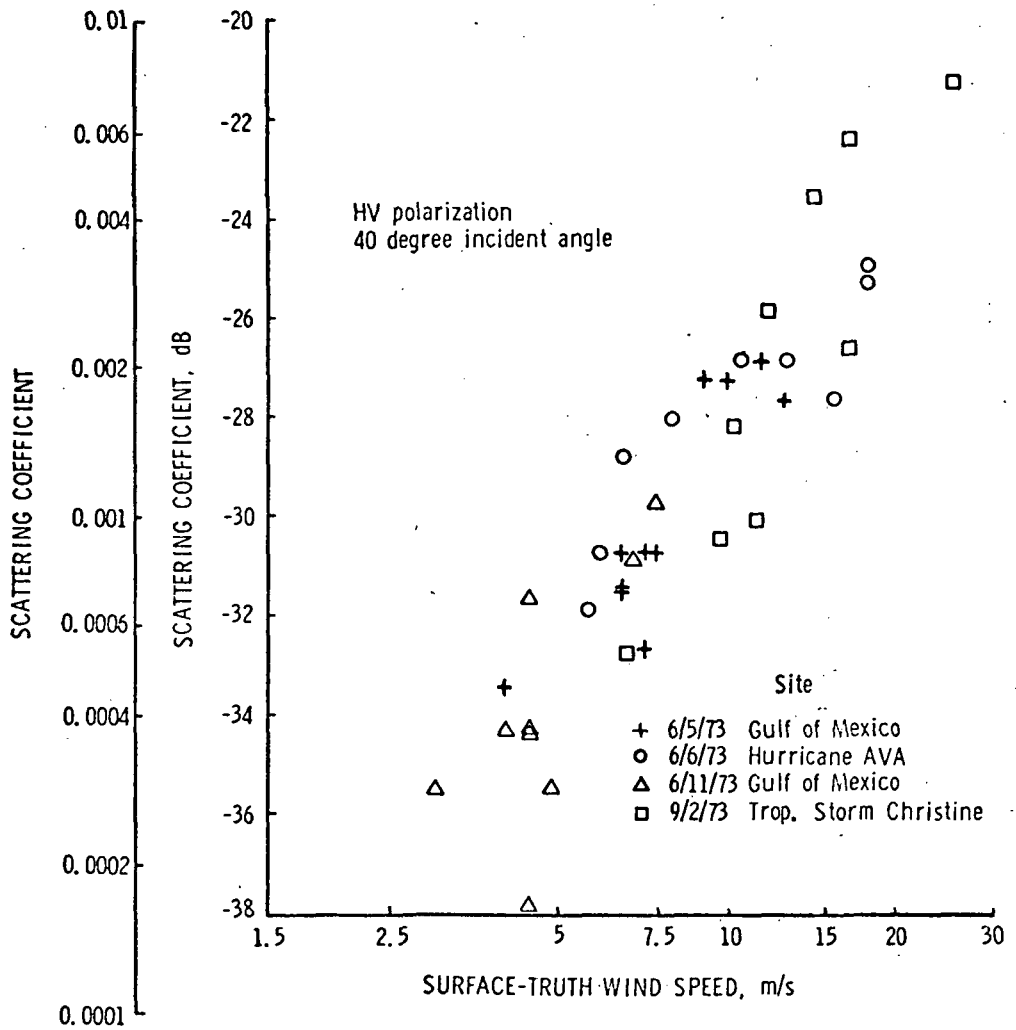
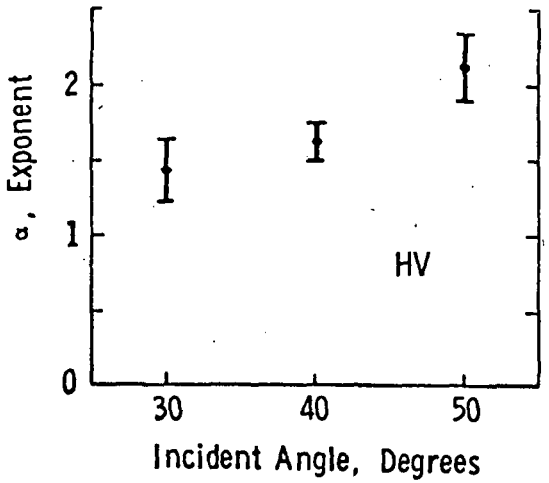


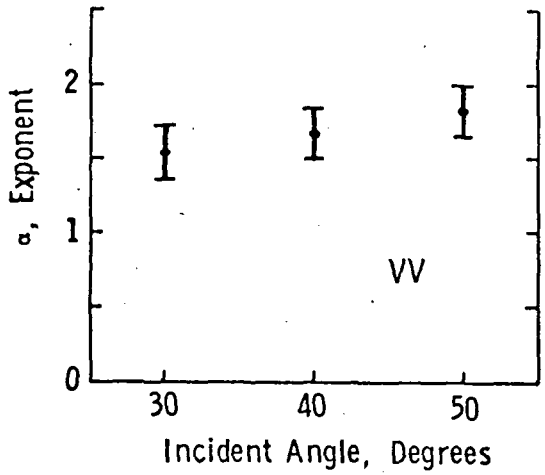
FIG. 10. WIND SPEED DEPENDENCE OF SCATTERING COEFFICIENTS (PRELIMINARY), HV POLARIZATION



Model: $\sigma^\circ = k w^\alpha$

where σ° is scattering coefficient
w is wind speed

Error bars indicate ± one estimated standard error



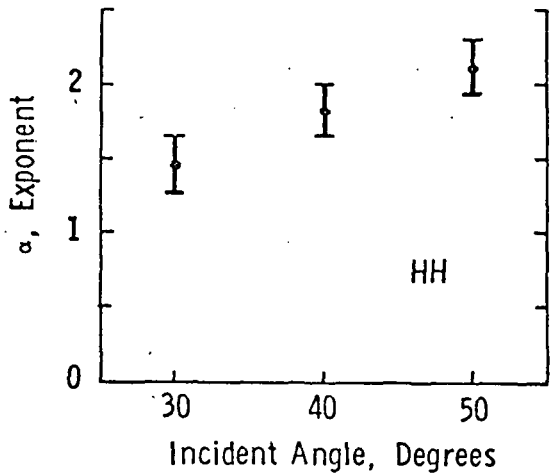


Fig. 11. Preliminary empirical estimates of the power law relating wind speed and scattering coefficient at 13.9 GHz (2.16 cm wave length)

A PROCEDURE FOR ESTIMATION OF SEA-SURFACE TEMPERATURE FROM REMOTE MEASUREMENTS IN THE 10 - 13 μm SPECTRAL REGION

M-4

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ABSTRACT

This paper demonstrates the feasibility of a procedure for the remote measurement of sea-surface temperature which inherently corrects for the effect of the intervening atmosphere without recourse to climatological data. The procedure relies upon the near-linear differential absorption properties of the infrared window region between 10 and 13 μm and requires radiometric measurements in a minimum of two spectral intervals within the infrared window which have a significant difference in absorption coefficient. The procedure has been applied to Nimbus 4 infrared interferometer spectrometer (IRIS) data and to Skylab EREP S191 spectrometer data, and it is demonstrated that atmospheric effects on the observed brightness temperature can be reduced to less than 1.0 Kelvin.

INTRODUCTION

Global measurement of sea-surface temperature (hereafter referred to as SST) on a daily basis is currently operational at NOAA's National Environmental Satellite Service (NESS) Center. SST data are archived after a rather complex analysis of data from the scanning radiometer (SR) aboard the NOAA-4 satellite. The procedure for extracting SST information from SR data is an extension of that of Smith and Rao [1]. Basically, infrared window measurements (10.5 - 12.5 μm) are converted to SST values, at degraded spatial resolution, with proper consideration of SR instrument noise, noise related to signal transmission, receiving, and processing, and after accounting for the effects of the intervening atmosphere based upon climatological data.

Because of inherent limitations in the single-channel scanning radiometer method of producing SST's, archived temperatures have limited accuracy and spatial resolution. The next generation of TIROS satellites, denoted TIROS-N series, will contain a five-channel advanced very high resolution radiometer (AVHRR), which will provide for improved SST retrieval. The first instrument to be flown, planned for FY 78, will contain four channels, with a fifth channel to be added on the fourth or fifth satellite in the TIROS-N series. The nominal spectral regions for each of the five channels are 0.55 to 0.9 μm, 0.72 μm to detector cutoff (approximately 1.0 μm), 3.55 to 3.93 μm, 10.5 to 11.5 μm, and 11.5 to 12.5 μm, which will be the fifth channel to be added. The spectral response of the first four channels has been finalized, however, the spectral response of the fifth channel is still open. Of major impact to SST measurement is the addition of the infrared channel from 3.55 - 3.93 μm and the division of the present infrared window channel, i. e., 10.5 - 12.5 μm, into two channels. The reason for the addition of the two infrared channels is to provide additional information to correct for the effects of atmospheric moisture on the observed radiance (which can be significant, particularly for warm and moist conditions) without recourse to climatological data.

Previous studies [2, 3, 4, 5] have indicated that the addition of a second channel in the infrared window, one somewhat less transparent than the other, would allow for compensation of the effects of absorption and emission by atmospheric water vapor without recourse to climatological or other supportive data. The investigations involved the use of radiative transfer models, and large field-of-view space acquired data, i. e., the

infrared interferometer spectrometer (IRIS) aboard Nimbus 4. Although the results were encouraging, they remain tentative until they can be verified by an experiment for which the sensor field-of-view is comparable to that which will be used on future TIROS satellites. The Skylab mission provided the first opportunity for such a verification experiment.

This paper describes the results of an investigation which utilized IRIS and S191 spectrometer data acquired during two of the three Skylab missions to validate the radiative transfer models used in the initial investigations, and test the validity and correctness of two-channel temperature estimating algorithms developed from the radiative transfer models. The results of the investigation indicated that a significant benefit will be derived by the addition of a second channel in the infrared window region. Specifically, without recourse to climatological data, the investigation indicated SST's could be estimated to within $1^{\circ}K$.[1] Although the spectral bands selected for the analysis yielded a satisfactory result, the investigation also indicated that the infrared window transmission function contains nonlinearities and uncertain aerosol effects which could have a significant impact upon the optimum choice of the two spectral channels. Since the present analysis was limited in scope it is recommended that a further analysis be performed before a final choice of spectral channels is made.

THEORETICAL BASIS OF REMOTE SST MEASUREMENT AT THERMAL INFRARED WAVELENGTHS

The spectral radiance emitted by an opaque body at wavelength λ is given by

$$L(\lambda, T) = \epsilon(\lambda) L^{bb}(\lambda, T) \tag{1}$$

where $\epsilon(\lambda)$ is the spectral emittance of the opaque body and $L^{bb}(\lambda, T)$ is the spectral radiance emitted by a blackbody. The latter is represented as

$$L^{bb}(\lambda, T) = \frac{2hc^2}{\lambda^5 \left(e^{hc/\lambda kT} - 1\right)} \tag{2}$$

where

T = the temperature of a blackbody
c = the velocity of light
h = Planck's constant
λ = wavelength
k = Boltzmann's constant

It is clear from these expressions that if the emittance is known, the temperature can be determined by measuring the emitted spectral radiance and inverting Eq. (1). The application of such a measurement procedure to determine the temperature of a water surface exposed to the atmosphere is more complex. The spectral emittance of a sea surface is less than 1 depending upon the emittance angle. Consequently, as one attempts to measure the emitted radiation, some sky radiation will be reflected from the water surface and collected by the infrared sensor. Also, since water does not become opaque to infrared radiation at thermal wavelengths until a depth of approximately 0.10 mm, some of the measured radiation emanates from below the surface, which generally has a slightly different temperature. Therefore, the temperature derived from a measurement of the radiance at the surface will be the temperature of a blackbody which yields an equivalent value of radiance (i. e., the "equivalent radiometric temperature"). It will be different from the actual surface temperature; the degree of difference

1- Temperature accuracies are based upon atmospheric effects only. Other sources of noise and accuracy degradation factors are not included.

will depend upon the magnitude of the reflected radiation and the temperature gradient near the surface.

The present analysis is not concerned with the relationship between the equivalent radiometric temperature and the actual surface temperature, but only with the effect of the atmosphere on the equivalent radiometric temperature derived from a radiometric measurement performed at satellite altitudes. Therefore, all future references to SST will refer to the equivalent radiometric temperature that would be derived from a radiance measurement at the surface.

Before reaching a spaceborne sensor, the spectral radiance emanating from the sea surface will be attenuated by atmospheric constituents, such as clouds, haze, and absorbing gases. These atmospheric constituents also emit and scatter radiant energy, which contributes to the total signal received by the sensor. The central problem in accurately measuring SST from space lies in determining the extent to which such effects can be observed and compensated.

To demonstrate more clearly the nature of the problem of measuring the sea temperature from space, consider the spectral radiance leaving the top of the atmosphere, $L(\lambda)$, which can be represented by:

$$L(\lambda) = L^{bb}[\lambda, T(P_o)]\tau(\lambda, P_o)\epsilon(\lambda) + \int_{\tau(\lambda, P_o)}^{1} L^{bb}[\lambda, T(P)]d\tau(\lambda, P) \qquad (3)$$

where

P_o is surface pressure
τ is atmospheric transmittance
P is atmospheric pressure
T is temperature

According to Eq. (3) estimating $T(P_o)$ from $L(\lambda)$ requires values of temperature, pressure, and the differential absorption properties of the atmosphere. Estimating SST from a single channel radiometric measurement is analogous to inverting Eq. (3) given temperature and pressure values consistent with the prevailing conditions which are obtained from either atmospheric soundings or climatological data.

To eliminate the requirement for ancillary data a scheme was devised which utilizes more than one spectral channel. The scheme was originally discussed and presented by Anding and Kauth [2], and subsequently discussed by McMillin [3] and Prabhakara [4]. The technique, like most remote sounding methods, is based on the use of the differential optical properties of the atmosphere in the infrared window region to infer the atmospheric attenuation. The attenuation values are then used to correct for the effect of the atmosphere on radiometric data.

Theoretical Basis of the Multi-Channel Method

Following the development of Prabhakara [4] the radiative transfer equation may be simplified as:

$$L(\lambda) = L^{bb}[\lambda, T(P_o)]\tau(\lambda, P_o)\epsilon(\lambda) + \overline{L^{bb}}(\lambda)\,[1 - \tau(\lambda, P_o)] \qquad (4)$$

where $\overline{L^{bb}}(\lambda)$ is the weighted mean Planck emission of the atmosphere.

In the infrared window region there are three primary contributors to the absorption. Local water vapor lines, H_2O continuum, and aerosols. The transmission functions for continuum absorption and aerosols are accurately represented by Beers Law. This is also true for selective line absorption when the absorption is either weak or the

individual lines are heavily overlapped. These conditions are approximately satisfied in the window region for one airmass. Hence, window transmission can be expressed as:

$$\tau = e^{-(k_\ell + k_c + k_a)u} = e^{-k_t u} \tag{5}$$

where k_ℓ, k_c, and k_a are the local line, H_2O continuum, and aerosol extinction coefficients, respectively. u is the effective absorber thickness. To a good approximation Eq. (5) can be represented by the first two terms of its series expansion, i.e.,

$$\tau \simeq 1 - k(\lambda)u \tag{6}$$

Substituting (6) into (4), and letting $\epsilon(\lambda) = 1$, we have

$$L(\lambda) \simeq L^{bb}[\lambda, T(P_o)] - \left\{ L^{bb}[\lambda, T(P_o)] - \overline{L^{bb}(\lambda)} \right\} k(\lambda)u \,. \tag{7}$$

Expanding the Planck function about the surface temperature $T(P_o)$ and retaining only the linear term we have

$$L^{bb}[\lambda, T] = L^{bb}[\lambda, T(P_o)] + \frac{\partial L^{bb}[\lambda, T(P_o)]}{\partial T} [T - T(P_o)] \,. \tag{8}$$

This approximation holds for a small wavelength region and a small range of temperatures. This relationship allows Eq. (7) to be expressed as:

$$T(\lambda) = T(P_o) - [T(P_o) - \overline{T}(\lambda)]k(\lambda)u \tag{9}$$

where $T(\lambda)$ is the brightness temperature of the observed radiance, $\overline{T}(\lambda)$ is the equivalent brightness temperature of the atmosphere, and $T(P_o)$ is the surface temperature. Eq. (9) shows a linear relationship between brightness temperature and absorption coefficient, provided $\overline{T}(\lambda)$ is not strongly dependent upon λ over the spectral region. A study by McMillin [3], and results of the present study, show variations of less than 5 per cent. Conceptually, therefore, measurements in only two wavelength intervals for which the respective absorption coefficients are significantly different are required to define the linear relationship.

To demonstrate the concept three wavelength intervals within the infrared window between 10 and 13 μm were chosen. Three intervals were chosen, rather than only two, to observe possible nonlinearities between brightness temperature and absorption coefficient. The intervals chosen were those used by Prabhakara [4], and are respectively, 10.25 - 11.25, 11.25 - 12.0, and 12.0 - 12.9 μm. This result is a consequence of selecting a 1 μm wide interval beginning at the long wavelength side of the 9.6 μm ozone band (the most transparent part of the window region) and then dividing the remaining wavelength interval into two equal wavenumber segments, each 56 cm^{-1} wide.

Absorption coefficient evaluation. - The mean absorption coefficient for each interval was evaluated empirically from transmission spectra computed from an analytical transmission code. For the infrared window region the code utilizes two absorption models; one for H_2O local line absorption and one for H_2O continuum absorption.

Local line absorption is represented by the Goody model [6] which is given by:

$$\tau(\lambda) = \exp\left[\frac{-(S/d)u}{\sqrt{1 + \frac{2}{\overline{P}} \left(\frac{S}{2\pi\alpha}\right) u}} \right] \tag{10}$$

where S/d = intensity to line-spacing parameter (cm^{-1})
u = absorber thickness (pr. cm.)
$\bar{P}$ = Curtis - Godson equivalent pressure (atm)
$\frac{S}{2\pi\alpha}$ = Intensity to half-width parameter (atm . cm^{-1})

The parameters S/d and $S/2\pi\alpha$ were evaluated from a tabulation of spectral line parameters [7] using a procedure discussed by Goody [6], modified to account for an instrument slit function. The parameters were evaluated at a spectral resolution of 10 cm^{-1} defined by the width of the slit function when the transmission is 50%. A comparison between band model and line-by-line derived spectra is shown in Figure 1. Observe that the transmission spectrum is well represented by the Goody model.

Continuum absorption in the window region results from two mechanisms; that caused by the wings of water vapor lines within the 6.3 μm band and the rotational water band which are pressure broadened by foreign gases, and that caused by the same water vapor lines which are self-broadened. The continuum absorption coefficient at total pressure P, and water vapor partial pressure p, is given by:

$$k(P,p) = k_1 P + k_2 p \tag{11}$$

where
k_1 is the absorption coefficient for foreign broadening at unit total pressure;
k_2 is the coefficient for self-broadening at unit water vapor partial pressure.

The values of k_1 and k_2 adapted for the continuum model are based upon a subjective analysis of the data of Bignell [8], Burch [9], and McCoy [10]. The values adopted for k_2 are illustrated in Figure 2. Discussions with Burch and Long indicated that a least-squares fit to the data would yield a self-broadening coefficient that was too high because of systematic errors for the larger data points and because of the consistency of the results of McCoy for the CO_2 lasing line at 10.59 μm. Therefore the selected values coincide with the lowest values shown.

The values adopted for k_1 are based upon the 10.59 CO_2 laser measurements of McCoy [10]. McCoy measured the transmission as a function of total pressure for a fixed water vapor pressure. Using the self-broadening coefficient (k_2) as a basis, the foreign-broadening coefficient (k_1) was determined to be 0.005 k_2.

Both k_1 and k_2 are temperature dependent, the value of k_1 increasing with increasing temperature and the value of k_2 decreasing with increasing temperature. For self-induced absorption the dependence was adopted from the work of Bignell [8] at 2 percent per degree Kelvin. For foreign-induced absorption the temperature dependence was scaled from the temperature dependence of the rotational water lines at 2 percent per degree Kelvin.

The empirical evaluation of the absorption coefficients was accomplished as follows. Ten atmospheric representations of temperature and humidity were selected from the NASA Four-Dimensional Model Atmosphere compilation [11], representing moist and dry conditions ($\pm$ one standard deviation from mean moisture conditions) for five oceanic global regions extending from the North Sea to the equator. These atmospheric data were input to the transmission code and spectral transmission from 10 to 13 μm was computed. These values were integrated over the respective wavelength intervals and transmission versus effective absorber thickness was plotted. The result is presented in Figure 3. Assuming transmission is accurately represented by Beers Law, i. e., $\tau = \exp(-ku)$, linear least squares fits to $\ln\tau$ versus u yielded three respective values for the absorption coefficient, which are also given in Figure 3.

To demonstrate the relationship between brightness temperature and absorption coefficient, the ten model atmospheres were input to atmospheric radiance codes and the vertical upwelling radiance at space altitudes, emanating from a sea surface whose temperature equaled $T(P_o)$ was calculated. To establish realism to the computations, and to add an additive source of noise, aerosol effects were included in the calculations. Specifically, two aerosol representations were selected, taken from the work of Fenn [12]. One whose optical properties and size distribution were consistent with a 100 percent maritime haze and the other with a 60 percent maritime haze and a 40 percent continental haze. The altitude distribution of aerosol density was assumed variable and controlled by the sea-level visibility. A 23 km visibility was used for the maritime haze, a 10 km visibility for the maritime-continental haze. The calculations of radiance were made by numerically evaluating Eq. (3), using the infrared window transmission described above to evaluate $d\tau(\tau, P)$. For each of the twenty spectra, in-band brightness temperatures were evaluated and plotted versus absorption coefficient. The results are shown in Figure 4a - 4e. The straight lines are least squares fits to the data.

Discussion of results. - Observe that a nonlinearity exists between brightness temperature and absorption coefficient, which diminishes at higher brightness temperatures. This occurs because the atmospheric brightness temperature increases approximately 5 percent at the longer wavelength regions, and the increase is observable at the lower brightness temperatures, but becomes nearly insignificant for brightness temperatures above 290° K. Also note that the atmosphere causes a decrease in the observed brightness temperature of the sea surface ranging from 2° K for the cool northern region to greater than 5° K for the warm equatorial region. The application of the technique does, however, estimate the input SST values to within $\pm$ 0.5° K. Furthermore, the 3-band estimate is insignificantly better than the 2-band estimate ($\pm$ 0.5° K compared to $\pm$ 0.3° K).

The application of the technique to actual space-acquired data is shown in Figures 5 and 6. For each of the six cases the brightness temperatures were taken from Prabhakara [4], which were measured by the IRIS instrument on Nimbus 4. Observe nearly perfect linearity is demonstrated and that excellent agreement is obtained between predictions and ship measurements for three of the cases (Figure 5). The reason for the discrepancy for the other three cases (Figure 6) is unknown, although it could be attributable to a decrease in surface emissivity resulting from a high sea state.

The utilization of Skylab EREP S191 data as a verification experiment fell far short of expectations because of instrument problems. Although the problems have been identified, their effects remain uncorrected. Of the eight test areas planned for usage only one gave results which were considered satisfactory. This was for the Monroe Reservoir on 10 June 1973. A circumstance of the spectrometer was that whenever the brightness temperature of the spectral radiance was significantly different than either the ambient calibration source temperature, or the temperature of the internal mirrors or dichroic, inaccurate data resulted. For the Monroe Reservoir the aperture brightness temperature was approximately equal to the internal instrument temperatures and accurate data were obtained.

During the overpass of EREP the surface temperature was measured with a Barnes PRT5 radiometer yielding an average value of 25° C. Also, temperature and humidity data were obtained by a local radiosonde. Both the surface temperature and radiosonde data were input to the radiative transfer model and the radiance at the S191 aperture was calculated. Also included in the calculation was a 23 km visibility continental haze. A comparison of measured and calculated radiance is presented in Figure 7. Generally, the agreement is very good. Minor differences are noted between 8 and 9 μm, probably caused by the reduced values of aperture brightness temperature. Of major concern for

the present study is the region between approximately 10.5 and 13.0 μm, where the agreement is within a few percent. It would appear from this comparison that the radiative transfer model is a reasonable representation of reality.

To examine the application of the SST estimation technique to this data, for both the EREP spectra and the model calculations, the inband brightness temperatures were computed and plotted versus absorption coefficient. Least-squares lines were fitted to the data and the results are shown in Figure 8. Observe that both the model calculations and the EREP data estimate a surface temperature within $\pm$ 1.0^{o} K of the recorded ground truth temperature.

CONCLUSIONS AND RECOMMENDATIONS

The results presented herein indicate that a significant benefit will be derived by the addition of a second channel in the infrared window region. Specifically, atmospheric-effect uncertainties can probably be reduced to less than 1.0^{o} K without recourse to climatological data. The technique is likely to produce a significant benefit for unusual conditions, such as warm moist atmospheres over cool waters or vice versa, when climatological data would yield a particularly poor result.

The results presented herein are based upon a study of limited scope, with recourse to a limited amount of data. Although the study results are indicative, it would be desirable to apply the technique to a broader data base before a final choice is made for the spectral bands to be used in the latter satellites of the TIROS-N series.

REFERENCES

1. W. L. Smith, P. K. Rao, R. Koffer and W. R. Curtis, "The Determination of Sea-Surface Temperature from Satellite High Resolution Infrared Window Radiation Measurements," Monthly Weather Review, Vol. 98, No. 8, Aug. 1970, pp. 604-611.
2. D. Anding and R. Kauth, "Estimation of Sea-Surface Temperature from Space," Remote Sensing of Environment, Vol. 1, 1970, pp. 217-220.
3. L. McMillin, A Method of Determining Surface Temperature from Measurements of Spectral Radiance at Two Wavelengths, Ph. D. dissertation, Iowa State University, 1971.
4. C. Prabhakara, B. Conrath, and V. Kunde, Estimation of Sea-Surface Temperature from Remote Measurements in the 11 - 13 μm Window Region, Goddard Space Flight Center, Greenbelt, MD, 1972.
5. J. Price, Analysis of Some Methods for Obtaining Sea-Surface Temperatures from Satellite Observations, Goddard Space Flight Center, Greenbelt, MD, 1973.
6. R. M. Goody, Atmospheric Radiation, I Theoretical Basis, Oxford at the Clarendon Press, 1964.
7. R. McClatchey, AFCRL Atmospheric Absorption Line Parameters Compilation, AFCRL, L. G. Hanscom Field, Bedford, Mass., AFCRL-TR-73-0096, Jan. 1973.
8. K. Bignell, Quar. Jour. Roy. Met. Soc., Vol. 96, 1970, p. 390.
9. D. Burch, Investigation of the Absorption of Infrared Radiation by Atmospheric Gases, Philco-Ford Corporation, Aeronutronic Division, Rept. No. U-4784, January 1970.
10. J. McCoy, D. Rensch and R. Long, Applied Optics, Vol. 8, No. 7, 1969.

11. D. Spiegler and J. Greaves, Development of Four-Dimensional Atmospheric Models (Worldwide), Allied Research Associates, Inc., Concord, Mass., NASA CR-61368, August 1971.

12. R. Fenn, Private Communications, AFCRL, Bedford, Mass., 1975.

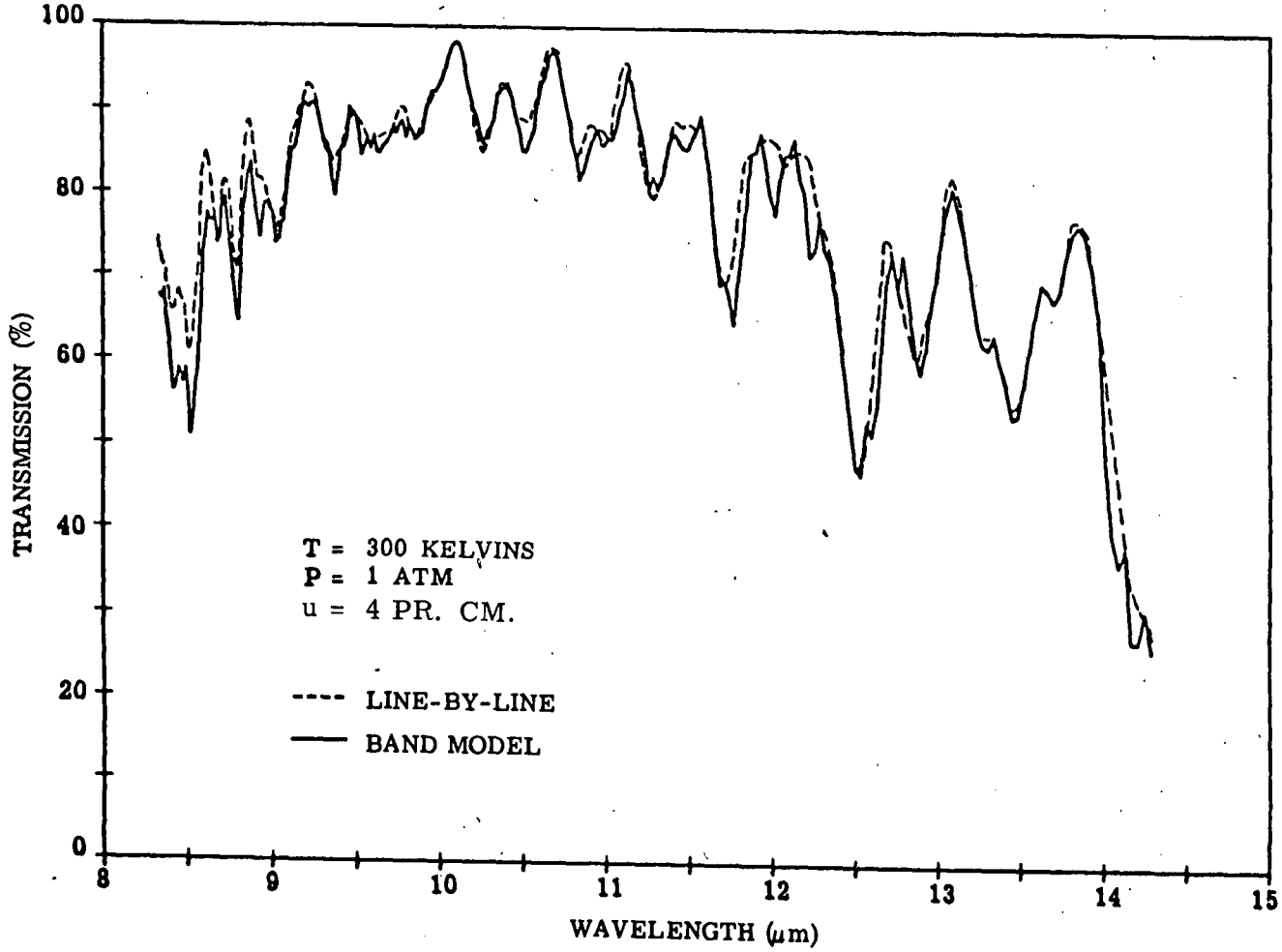


Figure 1. A Comparison of Band Model and Line-by-Line Derived Spectra for H_2O Local Line Absorption in the Infrared Window Region.

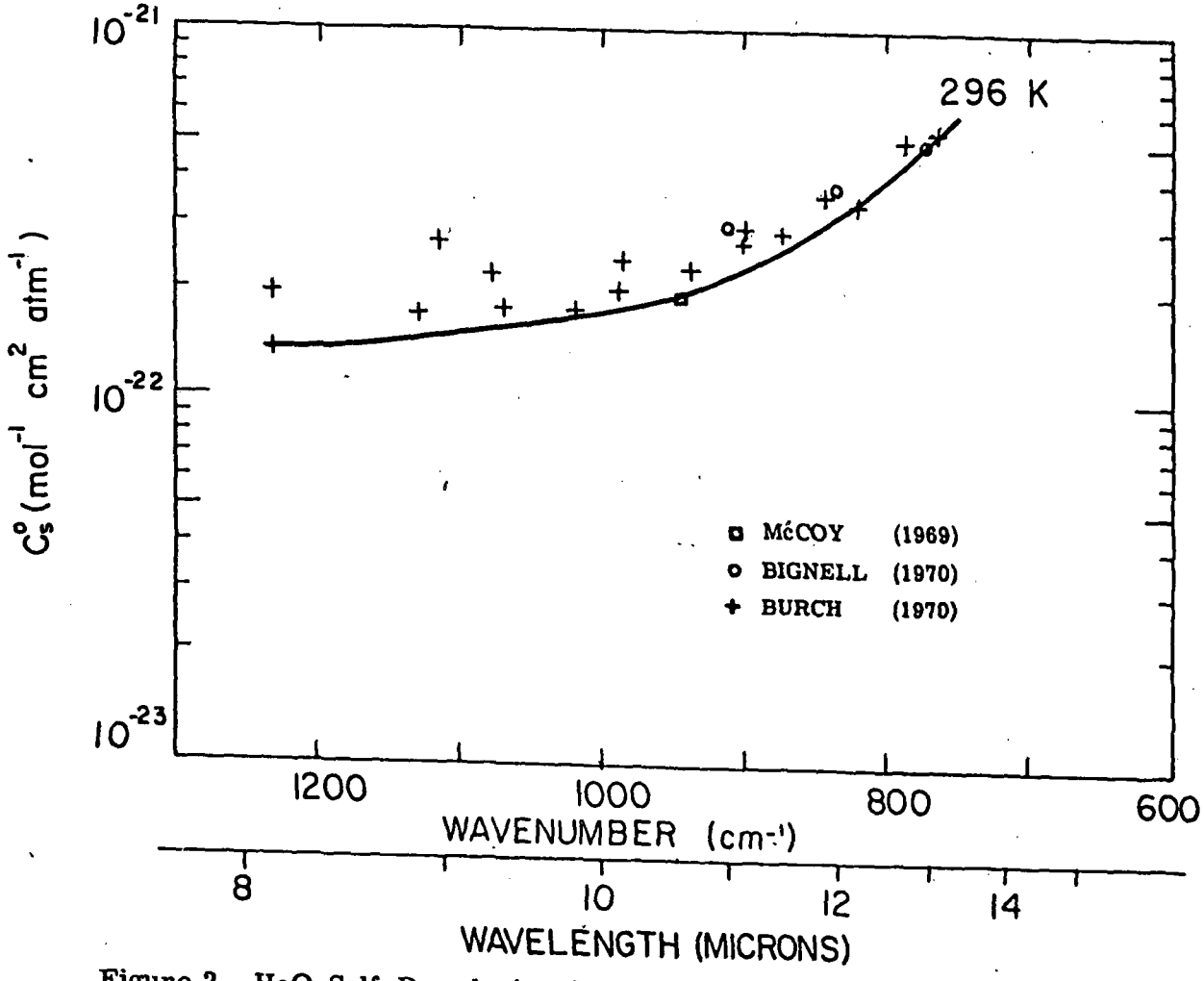


Figure 2. H_2O Self-Broadening Continuum Absorption Coefficient for Infrared Window Region.

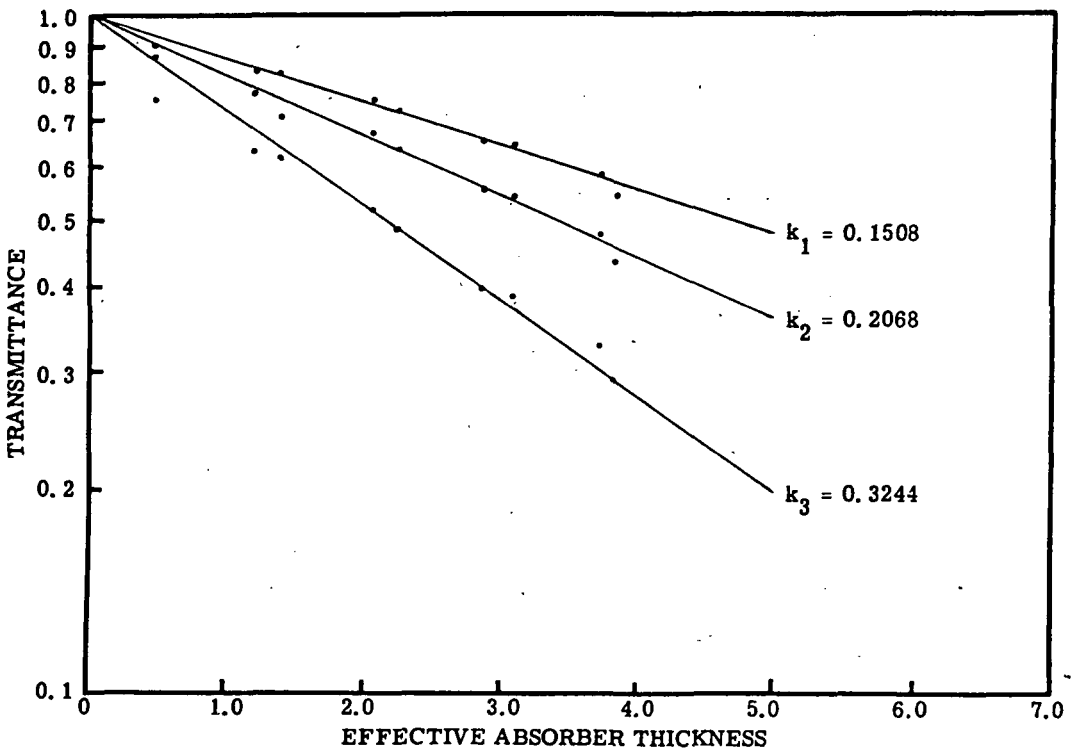


Figure 3. Average Transmission Versus Effective Absorber Thickness for Three Wavelength Regions (10.25 - 11.25, 11.25 - 12.0, 12.0 - 12.9 μm). k_1, k_2, k_3 are the respective Beers Law Absorption Coefficients.

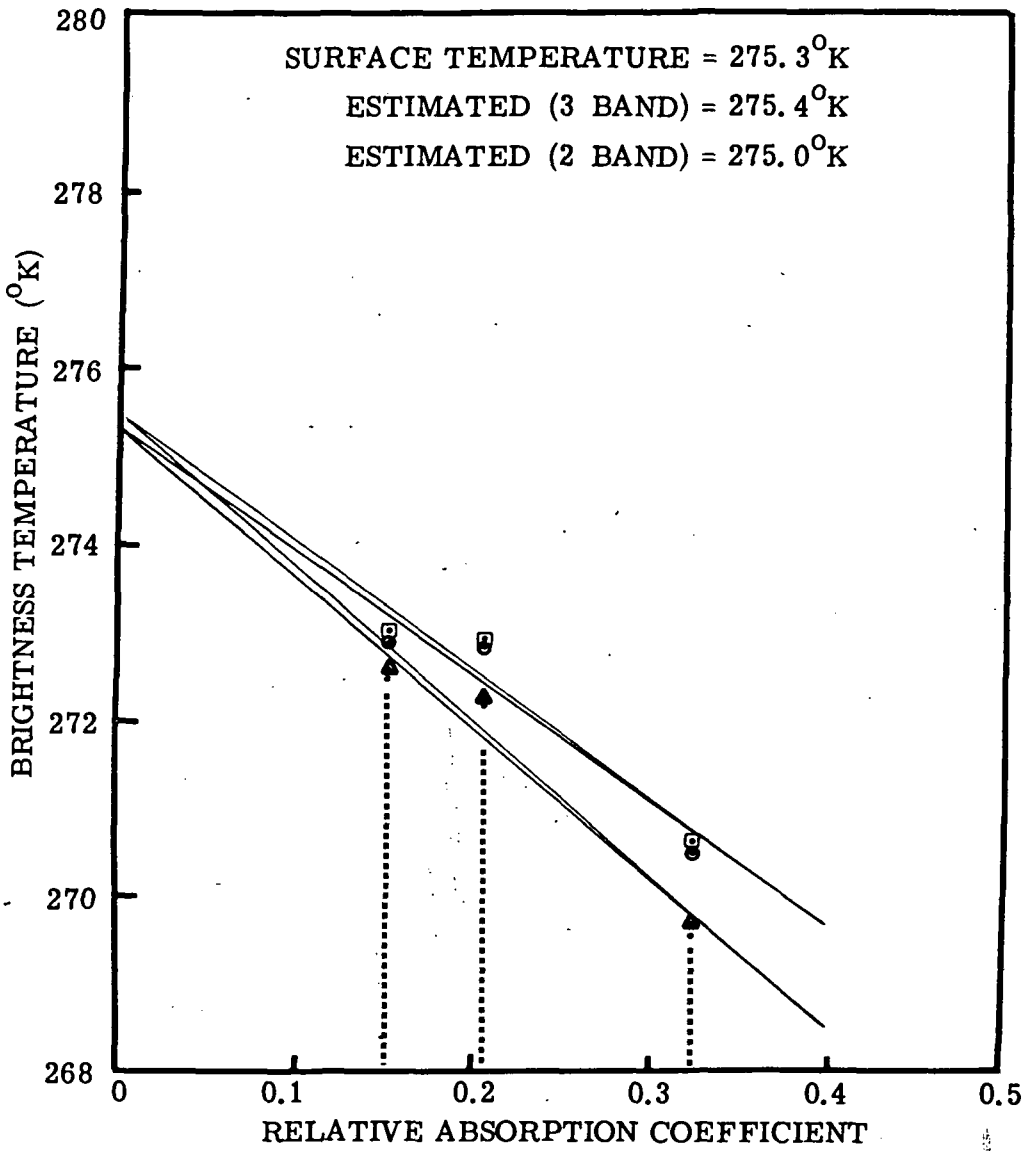


Figure 4a. Brightness Temperature Versus Absorption Coefficient.
Key: ⊡ Low Humidity, Continental-Maritime Haze;
● Low Humidity, Maritime Haze;
▲ High Humidity, Continental-Maritime Haze;
· High Humidity, Maritime Haze.

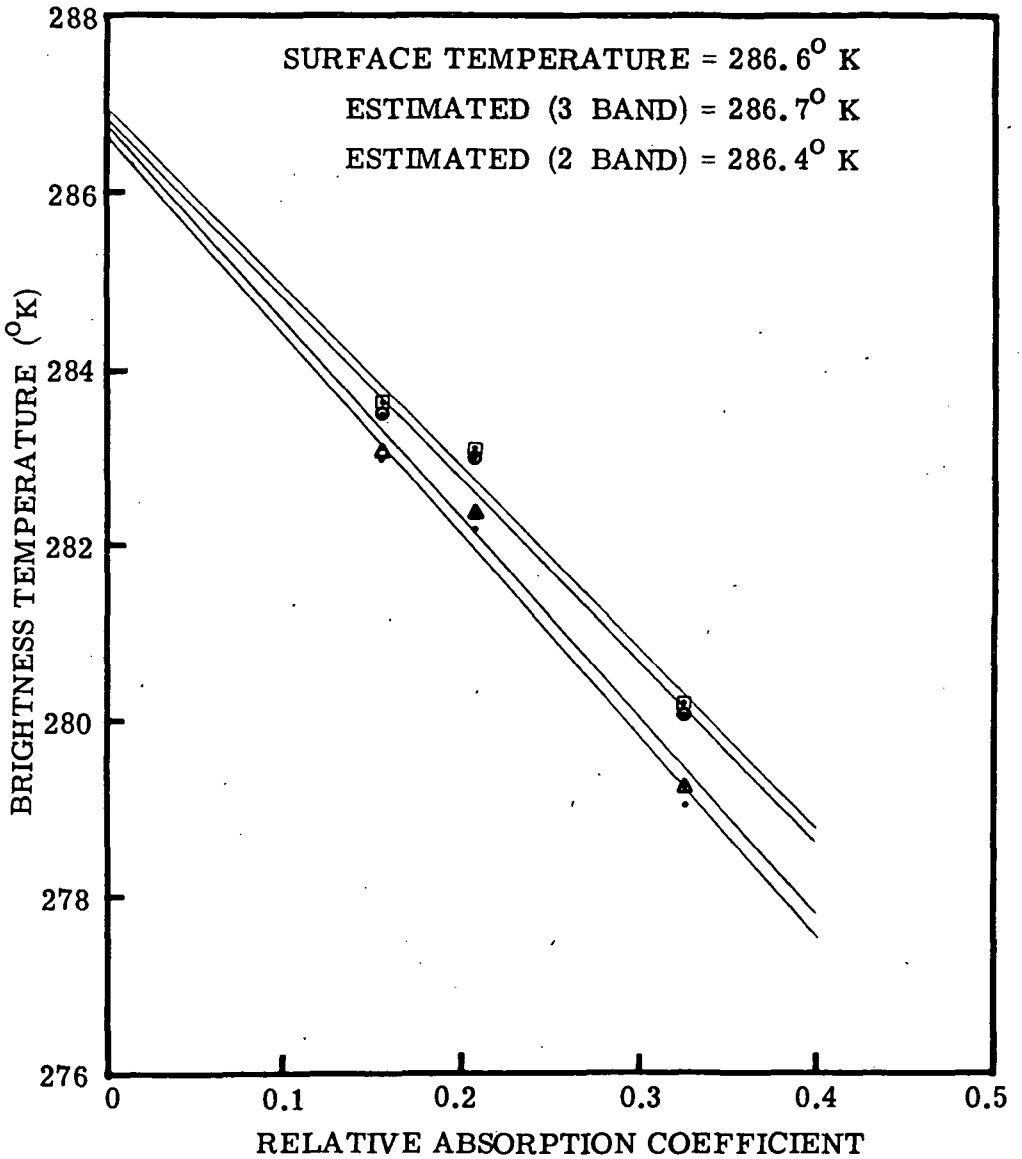


Figure 4b. Brightness Temperature Versus Absorption Coefficient.
Key: ▫ Low Humidity, Continental-Maritime Haze;
● Low Humidity, Maritime Haze;
▲ High Humidity, Continental-Maritime Haze;
· High Humidity, Maritime Haze.

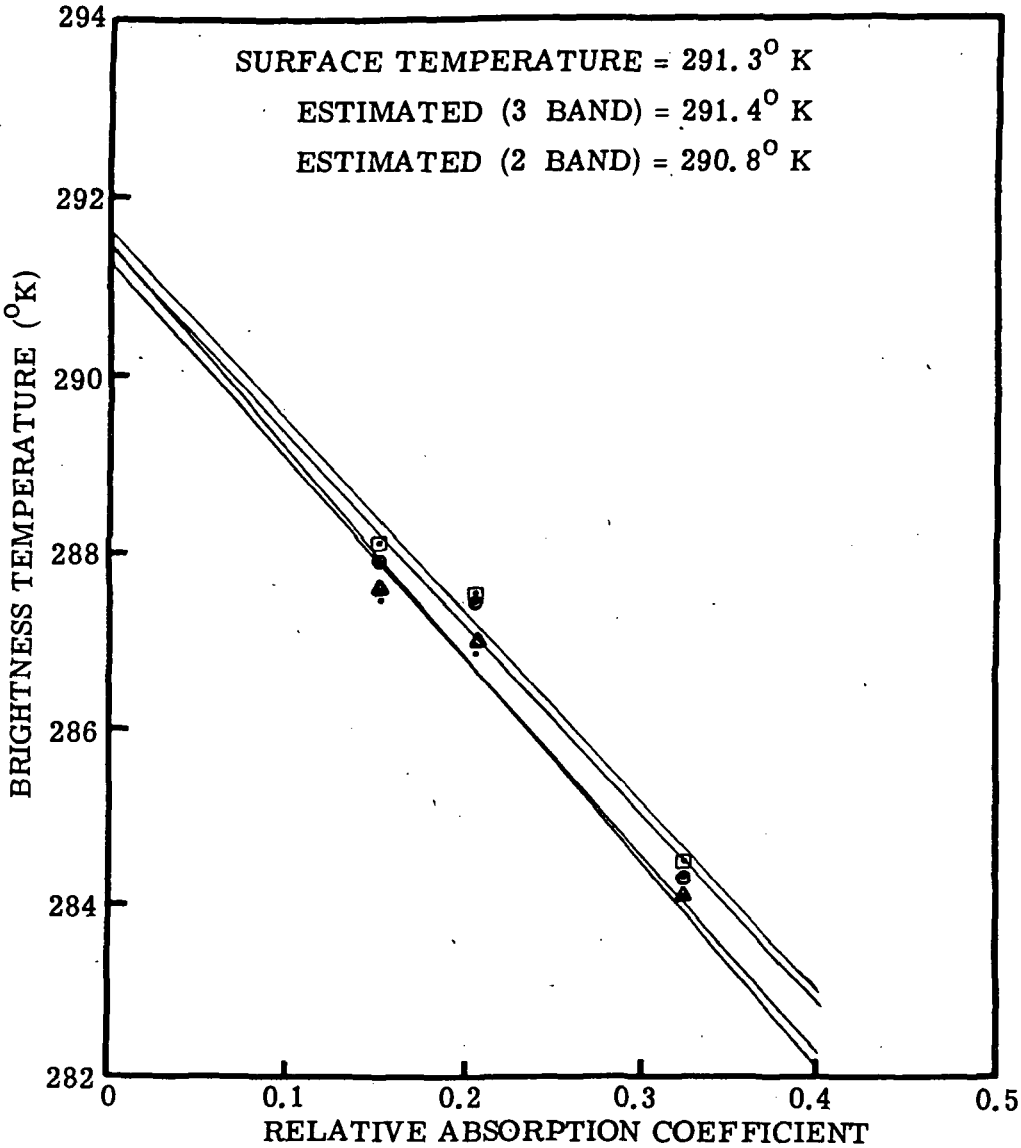


Figure 4c. Brightness Temperature Versus Absorption Coefficient.
Key: ⊡ Low Humidity, Continental-Maritime Haze;
● Low Humidity, Maritime Haze;
▲ High Humidity, Continental-Maritime Haze;
· High Humidity, Maritime Haze.

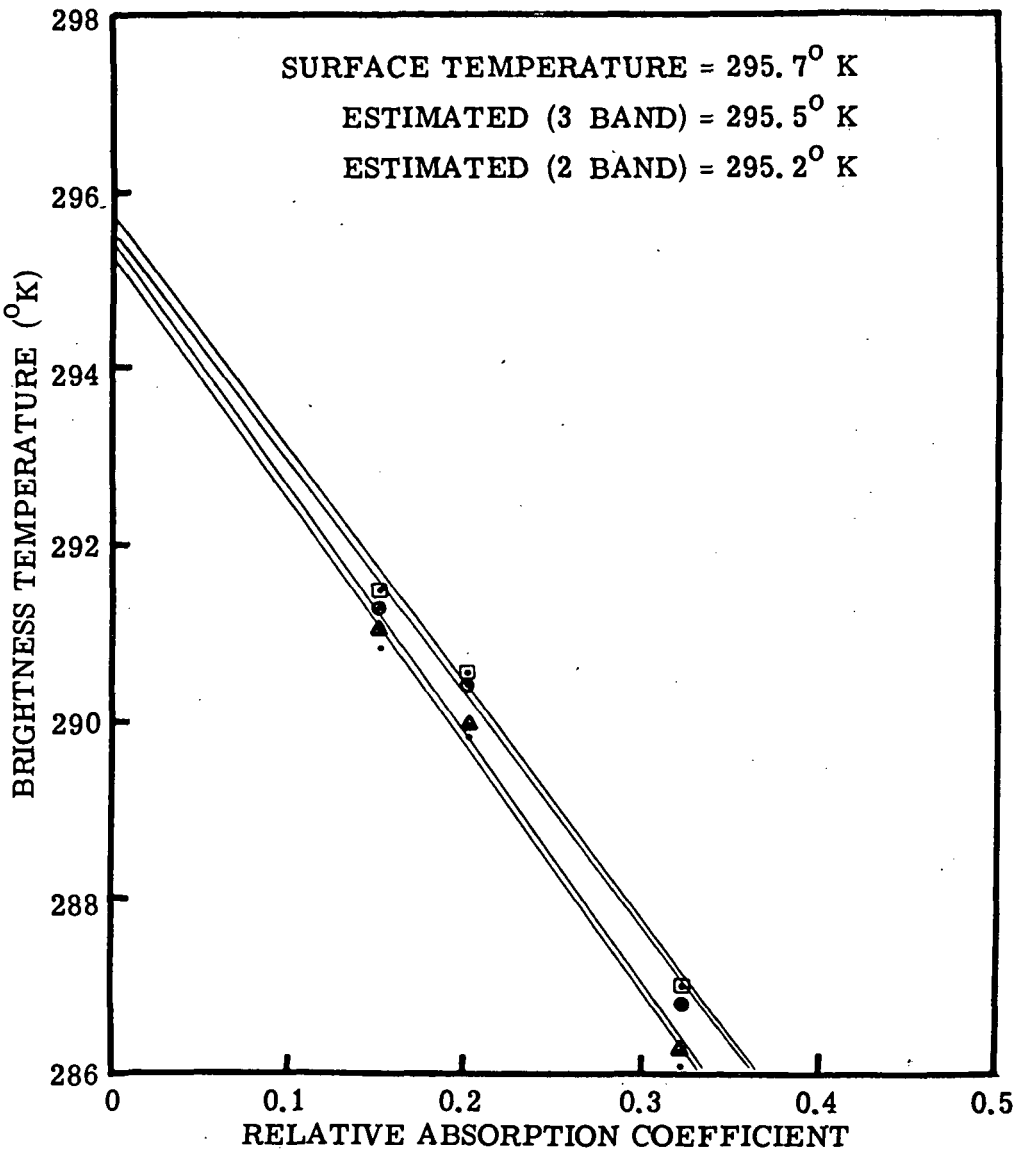


Figure 4d. Brightness Temperature Versus Absorption Coefficient.
Key: ⊡ Low Humidity, Continental-Maritime Haze;
⊙ Low Humidity, Maritime Haze;
△ High Humidity, Continental-Maritime Haze;
. High Humidity, Maritime Haze.

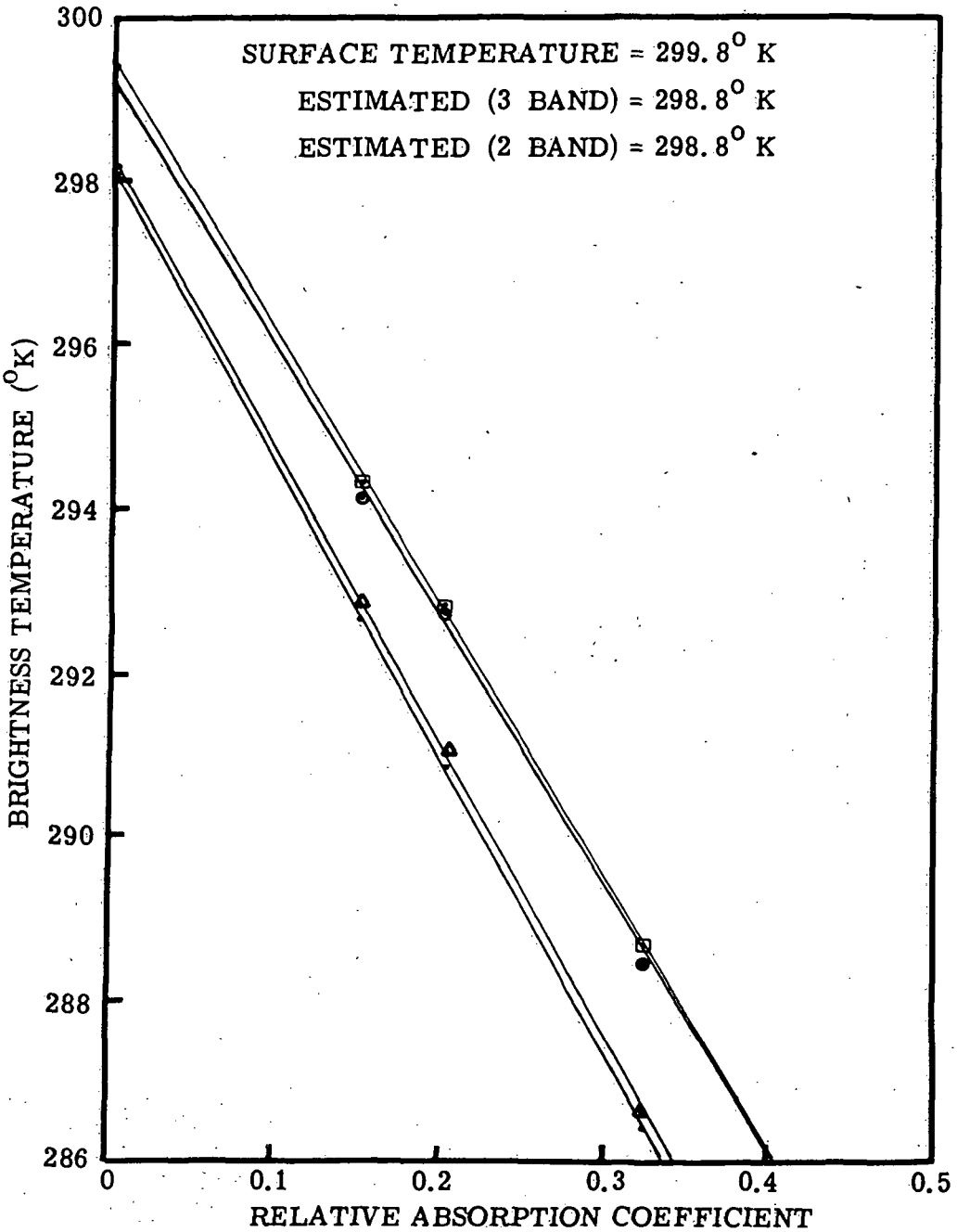


Figure 4e. Brightness Temperature Versus Absorption Coefficient.
Key: ⊡ Low Humidity, Continental-Maritime Haze;
⊙ Low Humidity, Maritime Haze;
▲ High Humidity, Continental-Maritime Haze;
△ High Humidity, Maritime Haze.

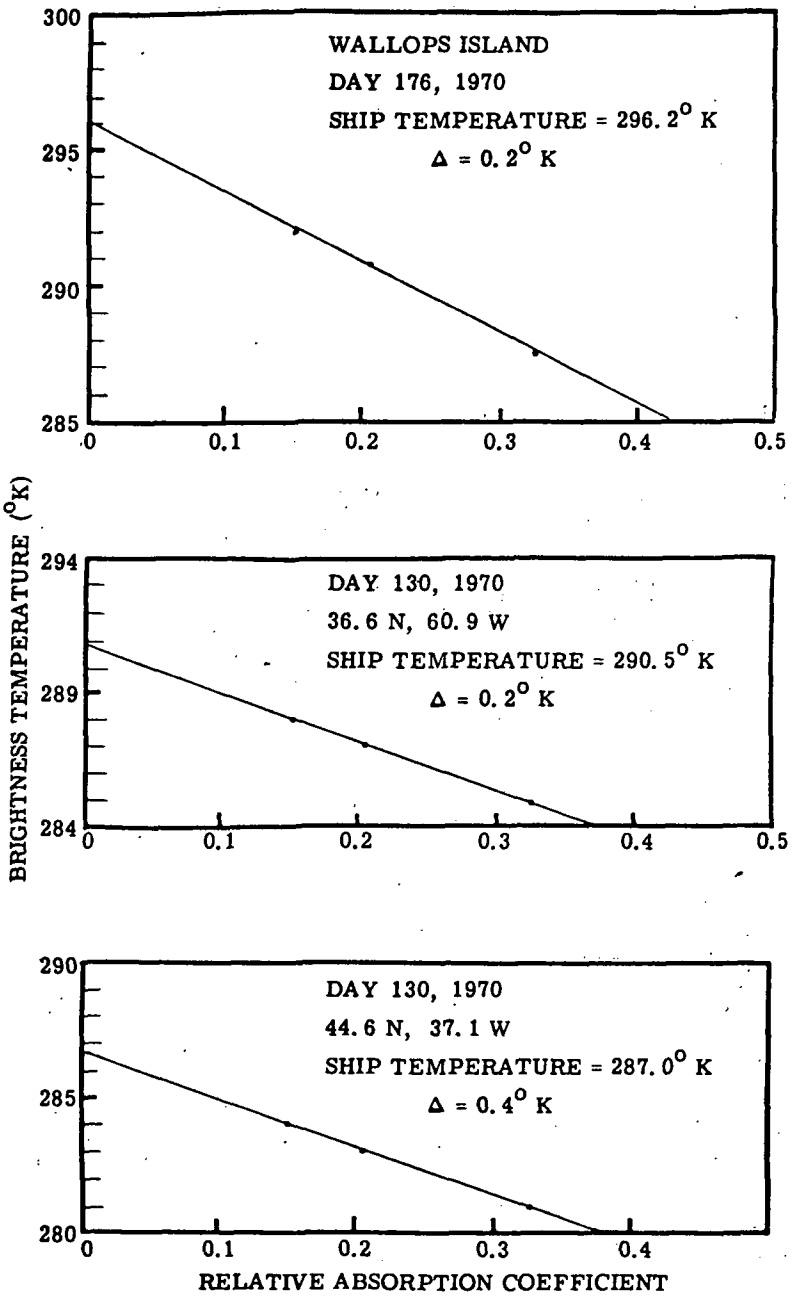


Figure 5. IRIS Measured Brightness Temperature Versus Relative Absorption Coefficient.

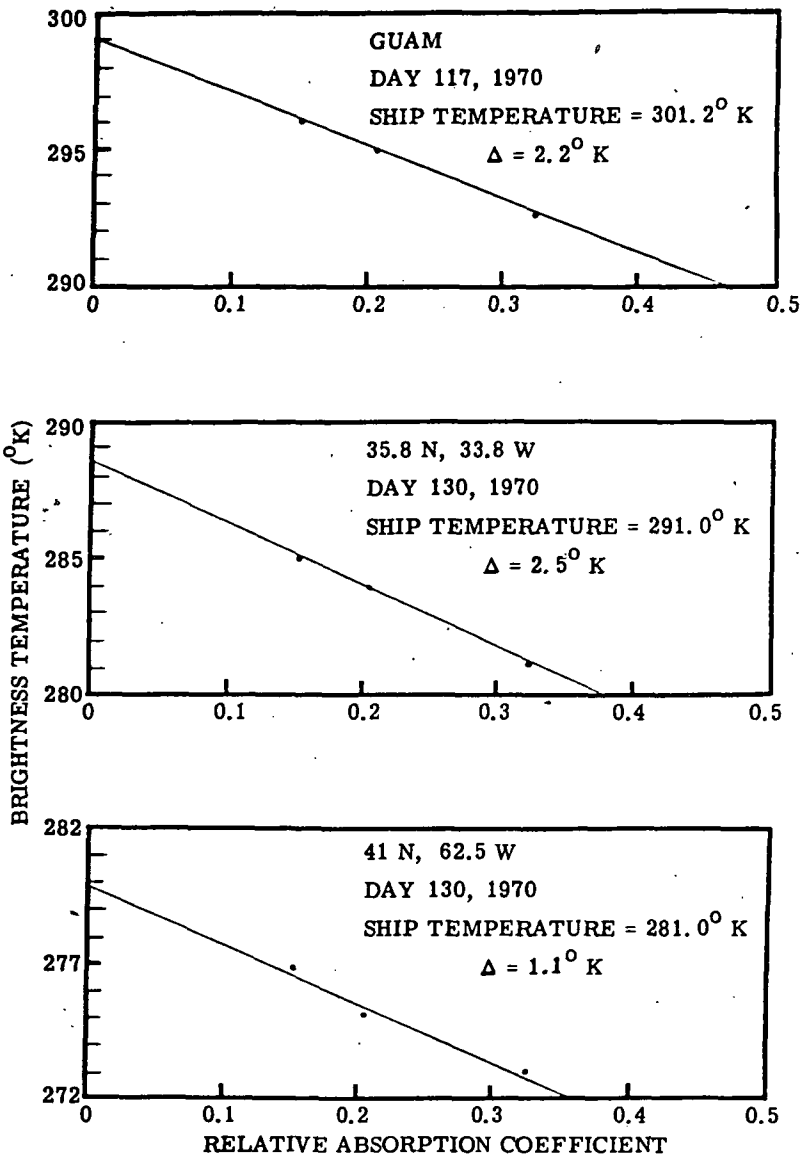


Figure 6. IRIS Measured Brightness Temperature Versus Absorption Coefficient.

1971

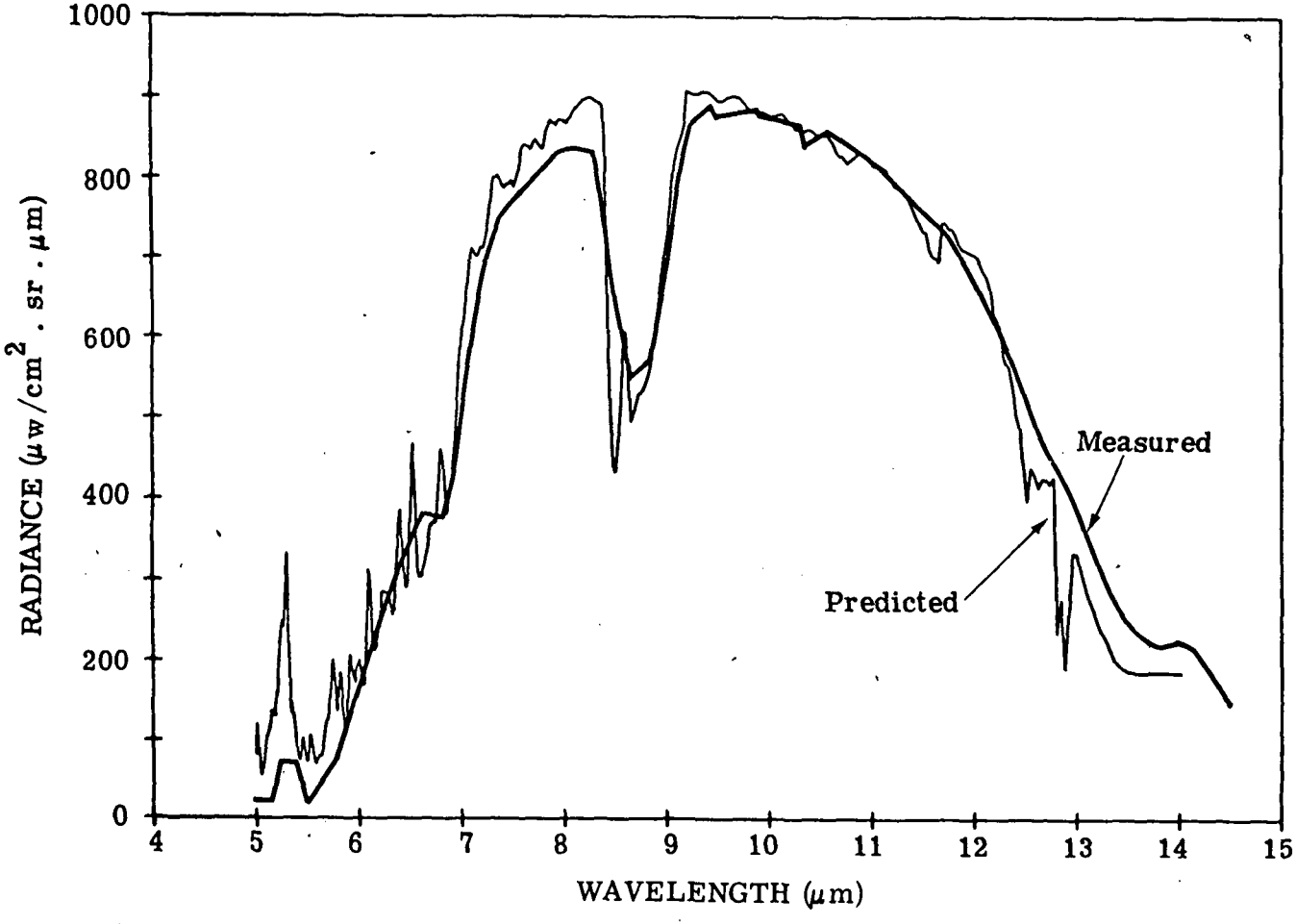


Figure 7. Comparison of Measured and Predicted Spectral Radiance for Monroe Reservoir, Salem, Illinois, on 10 June 1973. Water Surface Temperature = 298° K.

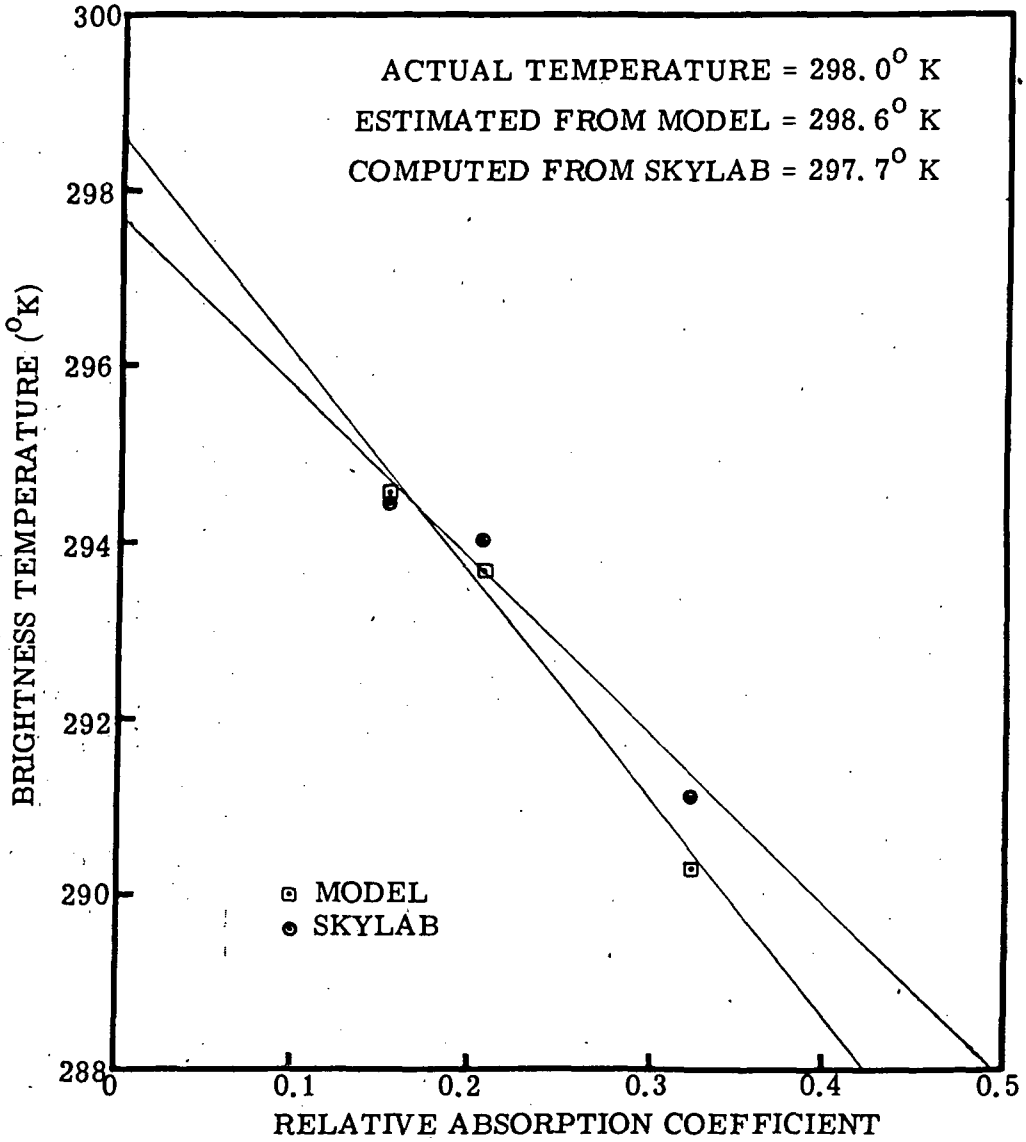


Figure 8. Brightness Temperature Versus Absorption Coefficient for Monroe Reservoir on 10 June 1973. Model Predictions Compared to S191 Measurement Predictions.

SURFACE CIRCULATION IN THE GREAT LAKES AS OBSERVED BY LANDSAT-1 AUGUST 1972-DECEMBER 1973: SOUTHERN LAKE MICHIGAN

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ABSTRACT

The surface current circulation patterns of southern Lake Michigan have been charted for all cardinal and subcardinal wind directions, employing LANDSAT-1 observations of the distribution of natural tracing material borne in the surface waters. These colorants consist chiefly of river discharges composed of suspended sediments, pollutants, and algae; extensive chemical precipitations proved valuable for areas farther from shore. Comparison of the satellite-derived surface current charts with previous theoretical and empirical studies shows good agreement.

INTRODUCTION

The LANDSAT-1 (formerly ERTS-1) system has added a new dimension to physical oceanography and limnology. Conditions permitting, scientists are now able to chart circulation patterns using natural tracing material borne in the surface waters. These colorants are chiefly turbidities from river discharges consisting chiefly of suspended sediments, pollutants, algae or natural dyes. Occasionally chemical precipitations are noted in the imagery (Figure 1); these, too, can be employed as circulation tracers, and they are particularly useful in areas farther from shore. Other sources of information are suspended sediment plumes originating from areas of shoreline erosion.

Synoptic oceanographic or limnologic investigations have always been difficult, if not impossible, from surface vessels. Circulation patterns are constantly being altered by changing meteorological conditions. The observation of naturally-occurring tracers from space, as a near-instantaneous "snap shot", provides circulation information that should relate to the meteorological influences at and immediately prior to the time of the satellite imagery.

METHOD OF ANALYSIS

Ayers (ref. 1,) has developed an empirical relationship that takes into account the large time lag between the onset of a given wind condition and the response of the surface circulation to this wind. A complete response of current to the wind requires many hours, or even several days. In Ayers' formula the resultant effective wind stress relationship is such that the forcing influence of the previous day is one-half that of the given day. In this Great Lakes investigation we have chosen to utilize three days of wind data prior to each LANDSAT-1 scene. In addition, to emphasize the 24-hour period immediately prior to the satellite data, we have represented the 6-hourly winds as a weighted resultant stress vector as follows:

$$\vec{W}_{(\text{day 1})} = \frac{\vec{W}_{(-24)} + 2\vec{W}_{(-18)} + 3\vec{W}_{(-12)} + 4\vec{W}_{(-6)}}{10}$$

The subscript after each vector wind observation denotes observation time (hours) before

noon of the day of the LANDSAT-1 observation.

A final vector resultant wind for the three-day period was obtained using the following formula:

$$\vec{W} = \frac{\vec{w}_{(\text{day } 3)} + 2\vec{w}_{(\text{day } 2)} + 4\vec{w}_{(\text{day } 1)}}{7}$$

For a more rigorous relationship one must take into account additional parameters such as atmospheric stability over the water, wave conditions, and current locations as a function of the distance to shore (ref. 2). Much of this fine-tuning, however, is not very realistic with the present paucity of wind data. In this study we have chosen to use the U.S. Coast Guard weather observations from shore installations rather than inland sites. Although these winds may suffer somewhat due to local anomalies in the wind field (e.g., lake breeze circulations), they are felt to be the most representative of true lake winds.

Circulation vectors have been extracted from each LANDSAT-1 scene using all natural or man-made tracers in the surface waters available to the analyst. As an illustrative example, the interested reader should compare the circulation derived for southern Lake Michigan under a northerly resultant wind (Figure 2) with the "whiting" image (Figure 1); the authors have discussed these extensive precipitations of calcium carbonate in detail elsewhere (refs. 3 and 4). Although complex, much of the analysis is straightforward in the hands of a trained interpreter.

Charts were prepared for all cardinal and subcardinal resultant wind directions (i.e., N, NE...NW). Some LANDSAT-1 observations of currents under a few wind directions were not available during the study period (August 1972 to December 1973). Whenever more than one LANDSAT-1 observation was used in a given area, the currents presented are composites. Although most of the current charts are based on only one LANDSAT-1 pass, if two scenes were available for a given resultant wind direction the observation under the stronger wind stress was generally used. It should be mentioned that circulation variations should be expected under weaker or stronger resultant wind stresses from the same direction. We have chosen to concentrate primarily on the direction of the wind vector rather than vector magnitude for this report.

Figure 3 shows the area covered by any given LANDSAT-1 pass.

The major difficulty encountered in the analysis of the LANDSAT-1 images was contamination by sunglint whenever the solar elevation exceeded 55° (ref. 4). Under these high sun angle conditions, current interpretations are subject to large errors. Future investigators should employ a sunglint-removal technique (e.g., MSS-6 minus MSS-5, (ref. 5) for more reliable results.

DISCUSSION

The locations of the wind information used in the preparation of the southern Lake Michigan current charts are shown in Figure 4. All locations referred to in the text are identified on this base chart. Only incomplete wind data were available from the Milwaukee and Muskegon Coast Guard facilities. Table I presents a summary of the LANDSAT-1 images that were analyzed in addition to the resultant wind directions calculated from the above formulae.

Northerly Winds

Figure 2 indicates the general surface circulation established by predominantly northerly light/moderate winds as derived from two cloud-free LANDSAT-1 passes (16 July

1973 and 21 August 1973). The latter pass (Figure 1) was particularly useful because that date marked the occurrence of an extensive $CaCO_3$ precipitation that was especially evident in MSS-4 (ref. 4). The major features established by this wind regime are several large gyres and distinct alongshore currents. An east shore southward current extends from Little Sable Point to Michigan City, where it becomes deflected to the northwest to become part of the eastern boundary of a large counterclockwise eddy off Chicago, first described by Ayers et al. (ref. 6) and confirmed by Bellaire (ref. 7). In this case, the eddy extends as far north as Waukegan. From Little Sable Point a branch of the east shore current flows southwestward and becomes incorporated in a second mid-lake counterclockwise gyre. This corresponds to the eddy noted by Bellaire (ref. 7) above the mid-lake sill between Milwaukee and Muskegon. A third eddy has a clockwise circulation and lies off Benton Harbor, Michigan, in the eastern part of the lake. This eddy has been previously observed (refs. 6 and 7), but here it is much smaller than reported previously. Along the Wisconsin shore at Milwaukee there may be a small nearshore clockwise eddy; it has been previously documented (ref. 6), but the evidence in the LANDSAT-1 images indicates only that there is a southward current some distance offshore.

Northeasterly Winds

Only one LANDSAT-1 pass was available for northeasterly wind conditions (17 July 1973), and only the Milwaukee area was sufficiently cloud-free to allow mapping of the sediment distribution patterns (Figure 5). The outflow current begins along the Wisconsin shore at Sheboygan and flows southward. After several days of northeasterly winds, water is transported onto the west shore from Milwaukee to Gary and is piled up there; on the slope of this wind set-up, the water flows southward and northeastward (ref. 6).

Easterly Winds

On 11 March 1973, LANDSAT-1 passed over the southeast portion of Lake Michigan. It was evident from the sediment patterns observed (Figure 6) that the east shore current flowed southward from Holland to Michigan City and then westward to Chicago. Off Michigan City is an apparent small flattened counterclockwise eddy, previously described by Ayers et al. (ref. 6) under a similar easterly wind regime. North of Benton Harbor a branch from the east shore current flows southwestward toward the middle of the lake, presumably to become part of the large clockwise gyre located along the shore between Holland and Benton Harbor. This is the same clockwise gyre discussed under Northerly Winds and documented by Ayers et al. (ref. 6) and Bellaire (ref. 7).

Southwesterly Winds

The current diagram (Figure 7) is a composite analysis of two LANDSAT-1 passes (10 June 1973 and 14 October 1973). The major feature evident in the figure has already been discussed--the large clockwise gyre along the east shore between Benton Harbor and Holland. The southward current along the east shore is very narrow under these southwesterly winds and it was not observed to extend south beyond Benton Harbor, where it turns westward to become incorporated into the eddy. According to the sediment distribution patterns, water is flowing northeasterly directly offshore from Chicago to the center of the lake. This apparent major upwelling has not been previously documented; Ayers et al. (ref. 6) and Bellaire (ref. 7) have described fully-developed gyres at this location. Offshore currents are indicated all along the west shore from Chicago to Sheboygan, suggesting that extensive upwelling was occurring. There may be a small clockwise gyre along the west shore at Waukegan, as suggested by Ayers et al. (ref. 6), but the satellite data are inconclusive.

Westerly Winds

Three cloud-free LANDSAT-1 passes (24 November 1972, 13 December 1972, and 4 May 1973) were composited to obtain the current diagram (Figure 8). The clockwise eddy along the east shore discussed above and previously (refs. 6 and 7) apparently has enlarged considerably from its size under other wind regimes. It now

extends from Benton Harbor north to Muskegon with a rather elongated shape. Between Gary and Michigan City lies a large counterclockwise gyre, which was discussed under Northerly Winds. In this case, however, the gyre has been displaced to the southeast as compared with other observations. Sediment distribution patterns suggest also the presence of a counterclockwise eddy above the mid-lake sill between Milwaukee and Muskegon; apparently a northwestward-flowing branch of the east shore southward current provides the driving force for this gyre. This was discussed under Northerly Winds. Alongshore currents converge in the Milwaukee - Racine area and then flow offshore, creating upwelling there and contributing to the circulation of the mid-lake eddy. A similar current convergence exists immediately north of Chicago in the Highland Park area; this offshore flow joins the east shore eddy system in the middle of the southern basin.

Northwesterly Winds

The diagram for northwesterly wind-generated currents (Figure 9) is based solely on one LANDSAT-1 pass (3 August 1973), which coincided with an extensive episode of calcium carbonate precipitation that turned the entire southern basin "milky" in MSS-4 (Figure 10). The east shore southward current is very narrow alongshore. Lakeward of that current is a long narrow band of upwelling from Benton Harbor to Muskegon; this was evident from the sunglint pattern on all four MSS bands. In the center of the lake is an elongated clockwise eddy that was discussed above and by Ayers et al. (ref. 6) and Bellaire (ref. 7); this wind regime has apparently displaced this gyre from the east shore toward the lake center. It extends from as far north as Milwaukee south to Benton Harbor. Between Milwaukee and Muskegon lies the mid-lake counterclockwise gyre discussed above; again it is driven by a westward branch of the east shore southward current that forms the northern boundary of the eddy. As discussed above, there is a flattened counterclockwise gyre from Gary to Benton Harbor driven by a branch current of the large central eddy and by the east shore southward current. Sediment patterns indicate a southward-flowing alongshore current at Chicago and suggest that a counterclockwise eddy exists there (refs. 6 and 7). Alongshore currents from Sheboygan to Highland Park are narrow and southward; at Racine and Highland Park they turn offshore (eastward), indicating upwelling at these locations.

CONCLUSIONS

The prevailing wind direction on Lake Michigan is southwesterly, although during winter northwesterly stresses are common. Along the western shore the current favors a northward direction, beginning with northeasterly to easterly winds, and probably (no LANDSAT-1 observations for easterly, southeasterly or southerly winds along this shore) continuing through southwesterly winds. Along the eastern shore a southward current appears dominant for all winds observed. South of Benton Harbor this flow reverses under southwesterly, westerly and northwesterly winds. The nearshore area between Michigan City, Indiana and Waukegan, Illinois contains an extremely complex circulation. Gyres in the central lake basin have been witnessed under southwesterly, westerly, northwesterly and northerly resultant wind regimes. Comparison with previously-observed, specific, localized circulations shows good agreement.

ACKNOWLEDGMENTS

The authors wish to express appreciation to NASA's Earth Resources Survey Program and their support through LANDSAT Contract S-70246-AG.

REFERENCES

1. Ayers, J.C. (1959a). Great Lakes waters, their circulation and physical and chemical characteristics. Paper presented to the Great Lakes Basin Symp., 29 December 1959, Chicago, Ill.

2. Jones, D.L. and F.R. Bellaire (1962). A numerical procedure for computing wind-driven currents on the Great Lakes. Proc. 5th Conf. on Great Lakes Res., Publ. #9, Great Lakes Res. Div., U. of Michigan, 93-102.

3. Strong, A.E., H.G. Stumpf, J.L. Hart and J.A. Pritchard (1974). Extensive summer upwelling on Lake Michigan during 1973 observed by NOAA-2 and ERTS-1 satellites. Proc. 9th Internat. Symp. on Rem. Sens. Environ., Environ. Res. Inst. of Michigan, Ann Arbor, 923-932.

4. Strong, A.E. and H.G. Stumpf (1974). An evaluation of ERTS data for oceanographic uses through Great Lakes studies. Final Report NASA/GSFC, Greenbelt, Md.

5. Watanabe, K. (1974). Detection of several sea states around Japan from multispectral scanner imageries by ERTS-1. Proc. 9th Internat. Symp. on Rem. Sens. of Environ., Environ. Res. Inst. of Mich., Ann Arbor, 1353-1354.

6. Ayers, J.C., D.C. Chandler, G.H. Lauff, C.F. Powers and E.B. Henson (1958). Currents and Water Masses of Lake Michigan, Great Lakes Res. Inst., U. of Michigan, 169 pp.

7. Bellaire, F.R. (1964). A comparison of methods of current determinations. Proc. 7th Conf. on Great Lakes Res., Great Lakes Res. Div., U. of Michigan, 171-178.

8. Ayers, J.C. (1959b). The Currents of Lakes Michigan and Huron, Great Lakes Res. Inst., U. of Michigan, 51 pp.

TABLE I - LANDSAT-1 FRAMES USED FOR SURFACE CIRCULATION CHARTS OF SOUTHERN LAKE MICHIGAN

Resultant Wind Direction	Orbit #	Date	ID #	Sun Elevation
N	4991	16 Jul 73	1358-16040	58*
			1358-16042	58*
	5493	21 Aug 73	1394-16030	50
			1394-16033	51
			1394-16035	52
NE	5005	17 Jul 73	1359-16094	58*
E	3220	11 Mar 73	1231-15591	36
			1231-15593	37
SE	NONE	NONE	NONE	NONE
S	NONE	NONE	NONE	NONE
SW	4489	10 Jun 73	1322-16042	60*
			1322-16045	61*
	6246	14 Oct 73	1448-16021	34
			1448-16023	35
W	1728	24 Nov 72	1124-16043	23
			1124-16050	24
	1993	13 Dec 72	1143-16102	20
	3973	4 May 73	1285-15590	55*
			1258-15592	56*
NW	5242	3 Aug 73	1376-16034	55*
			1376-16041	55*

* - Solar elevation equal to or greater than 55°. (Possible sunglint contamination and confusion with sediment features used for circulation charting.)

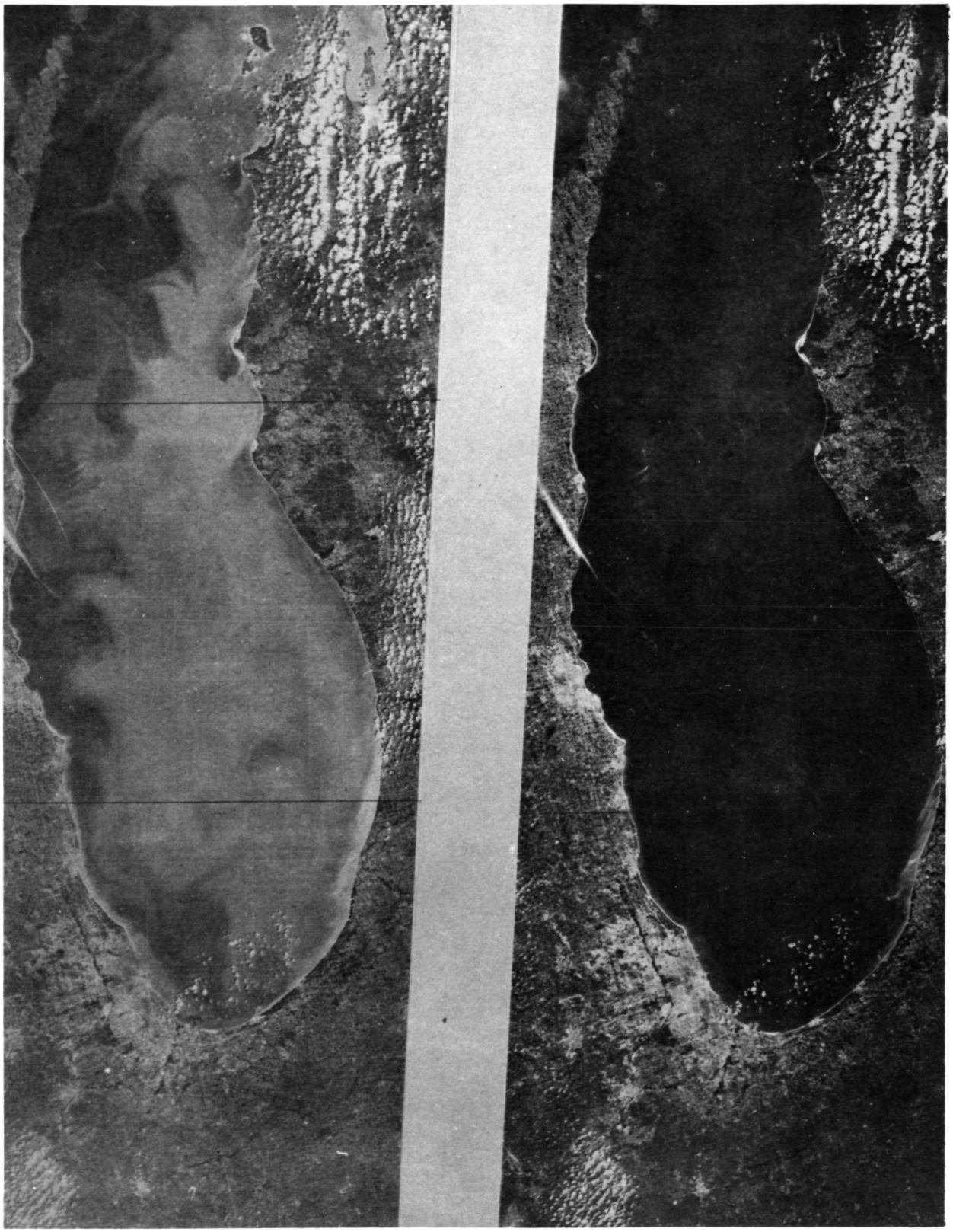


Figure 1. LANDSAT-1 images (MSS-4, left and MSS-5, right) obtained 21 August 1973, showing the extent of the calcium carbonate precipitation over southern Lake Michigan.

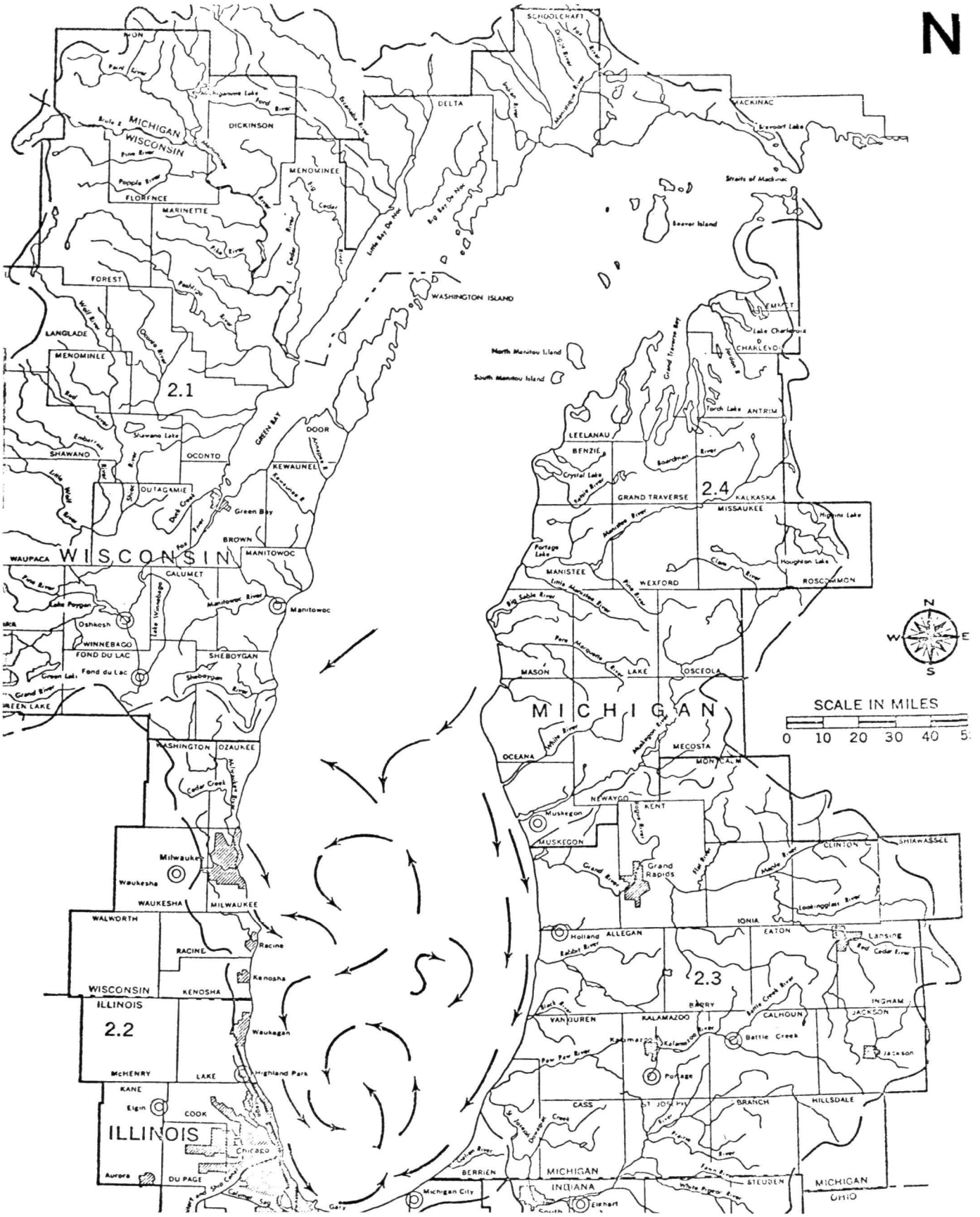


Figure 2. Surface current analysis as determined from turbidity patterns in LANDSAT-1 scenes. Weighted wind direction (Northerly) indicated in upper right-hand corner.

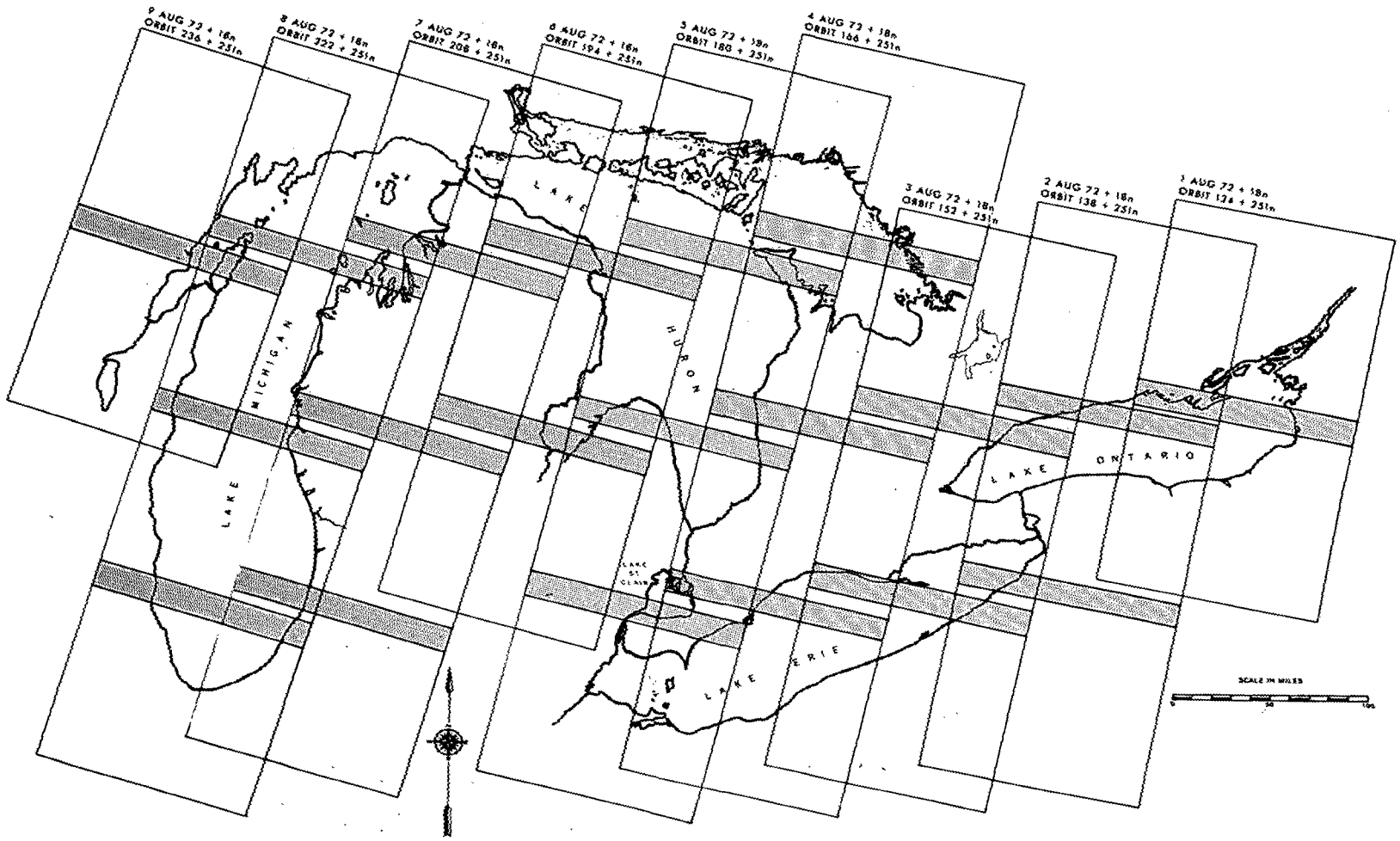


Figure 3. LANDSAT-1 coverage of the Great Lakes, excluding Lake Superior. Stippled areas indicate overlap.

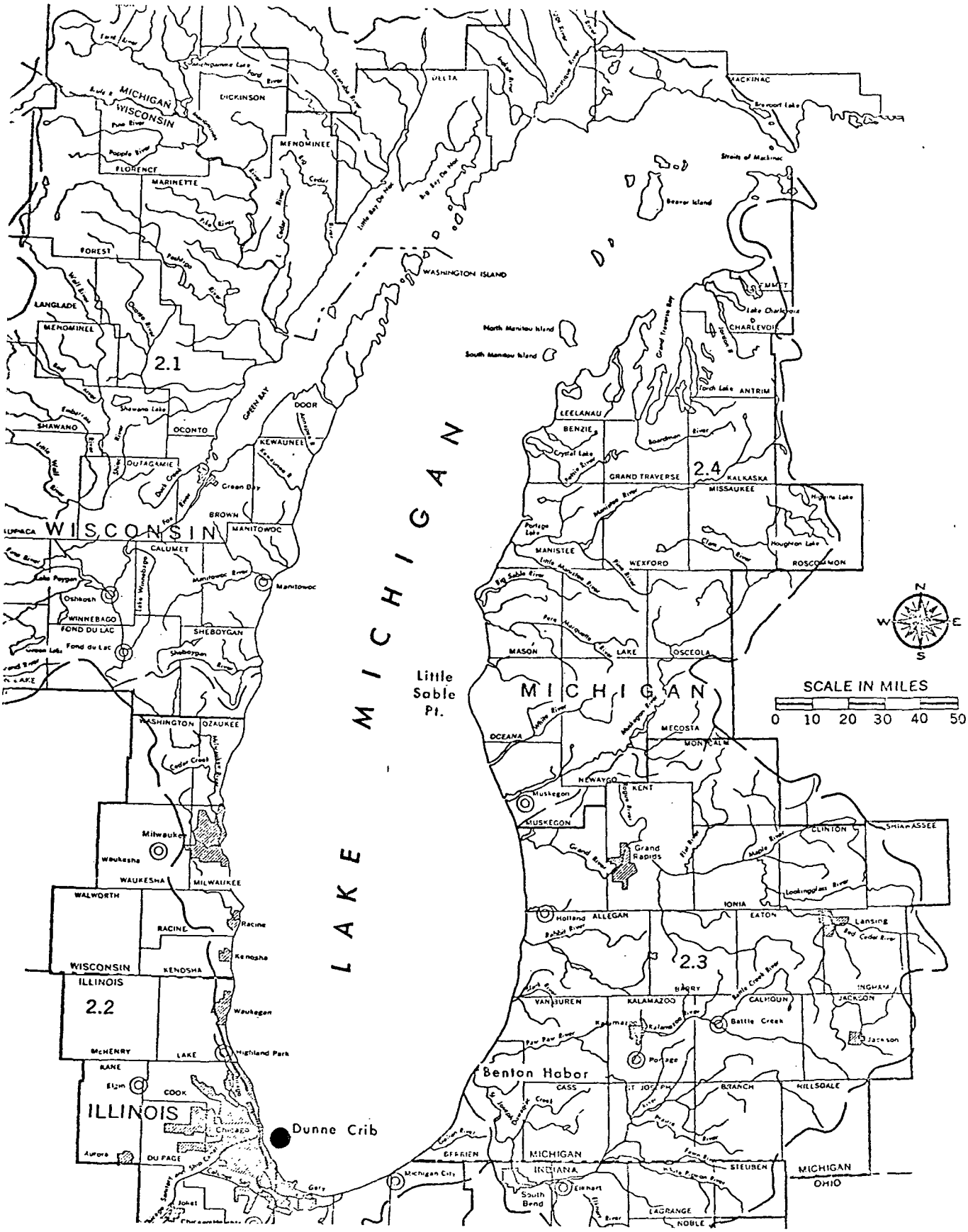


Figure 4. Wind station used for southern Lake Michigan (Dunne Crib-Chicago).

1982

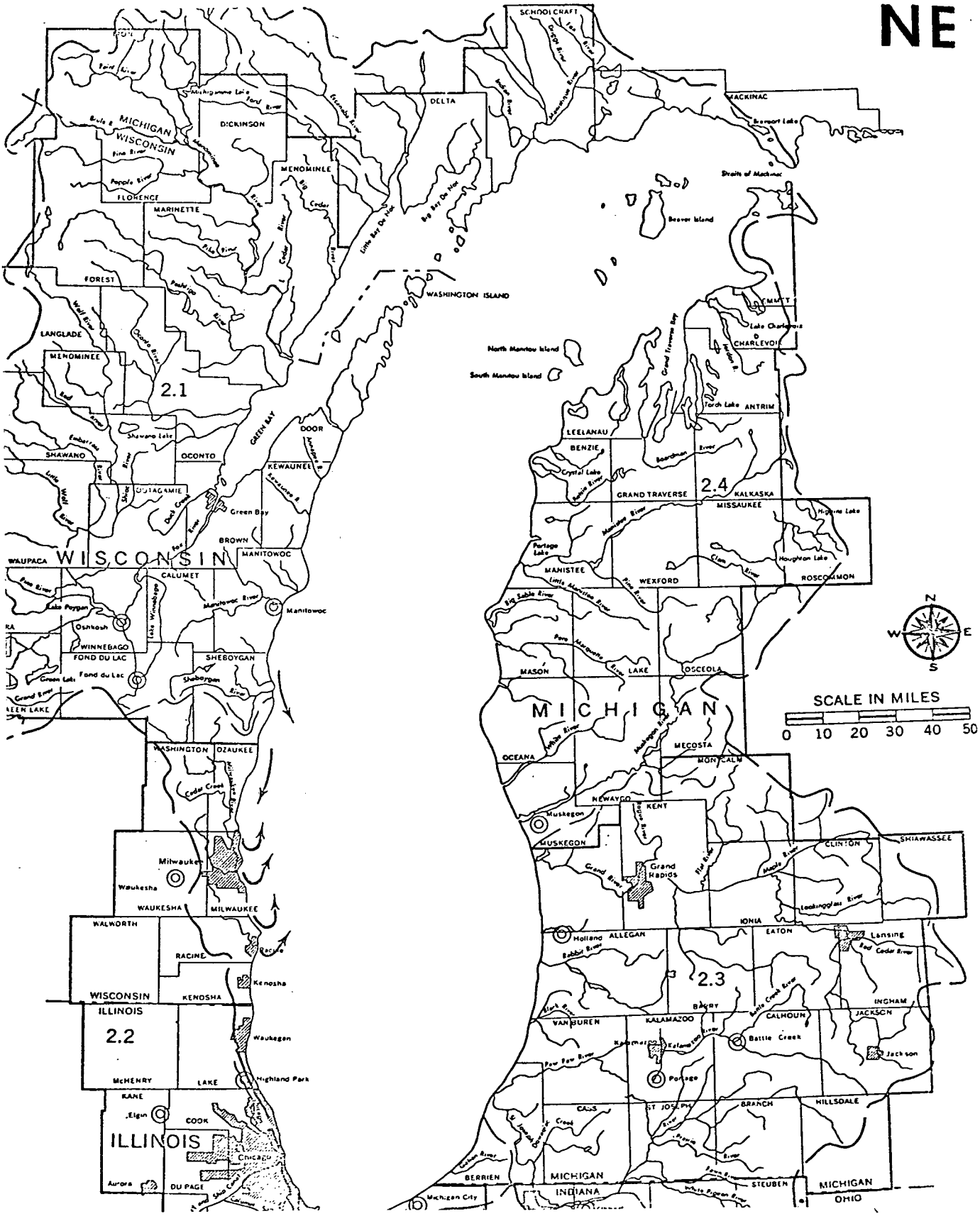


Figure 5. Surface current analysis as determined from turbidity patterns in LANDSAT-1 scenes. Weighted wind direction (Northeasterly) indicated in upper right-hand corner.

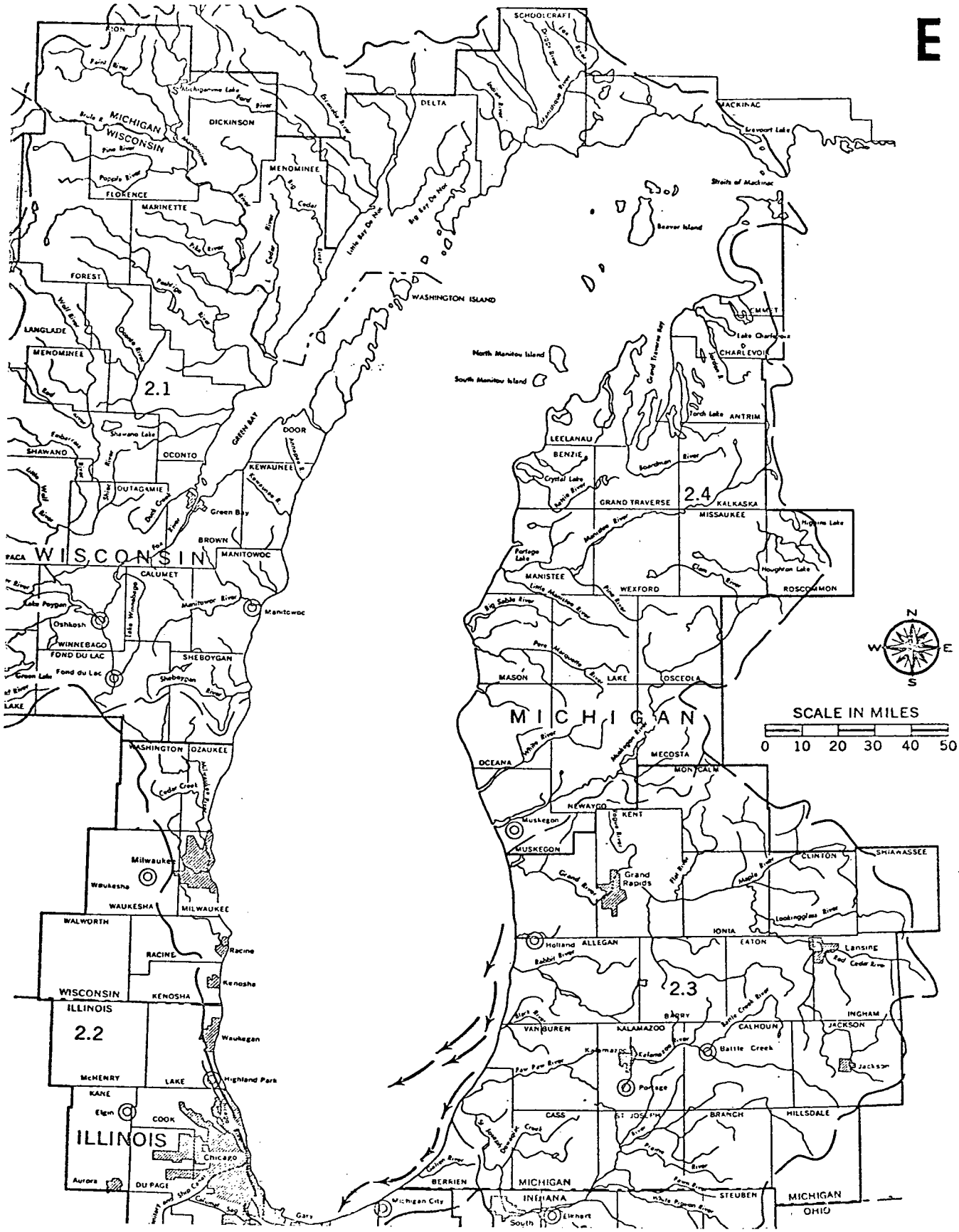


Figure 6. Surface current analysis as determined from turbidity patterns in LANDSAT-1 scenes. Weighted wind direction (Easterly) indicated in upper right-hand corner.

1984

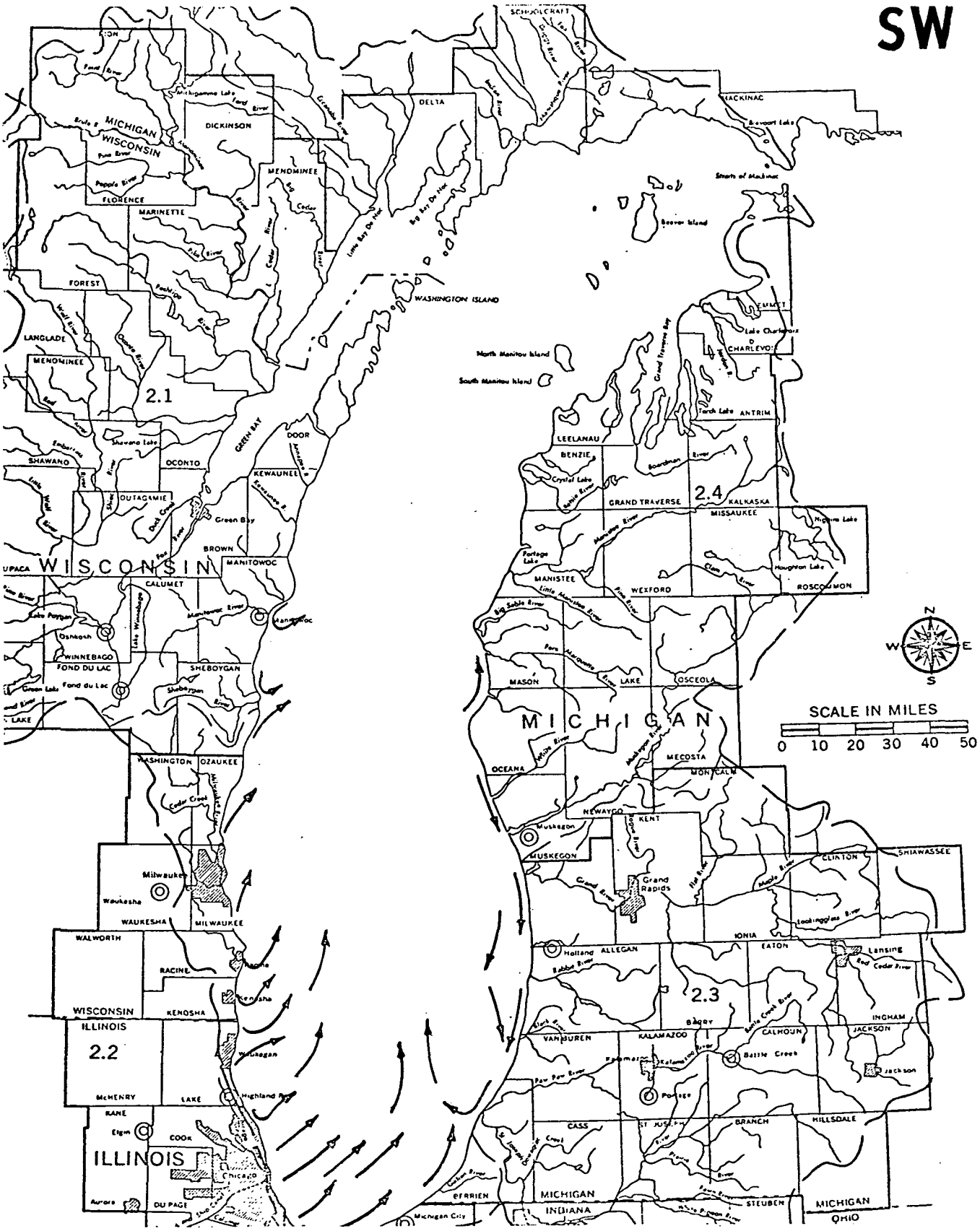


Figure 7. Surface current analysis as determined from turbidity patterns in LANDSAT-1 scenes. Weighted wind direction (Southwesterly) indicated in upper right-hand corner.

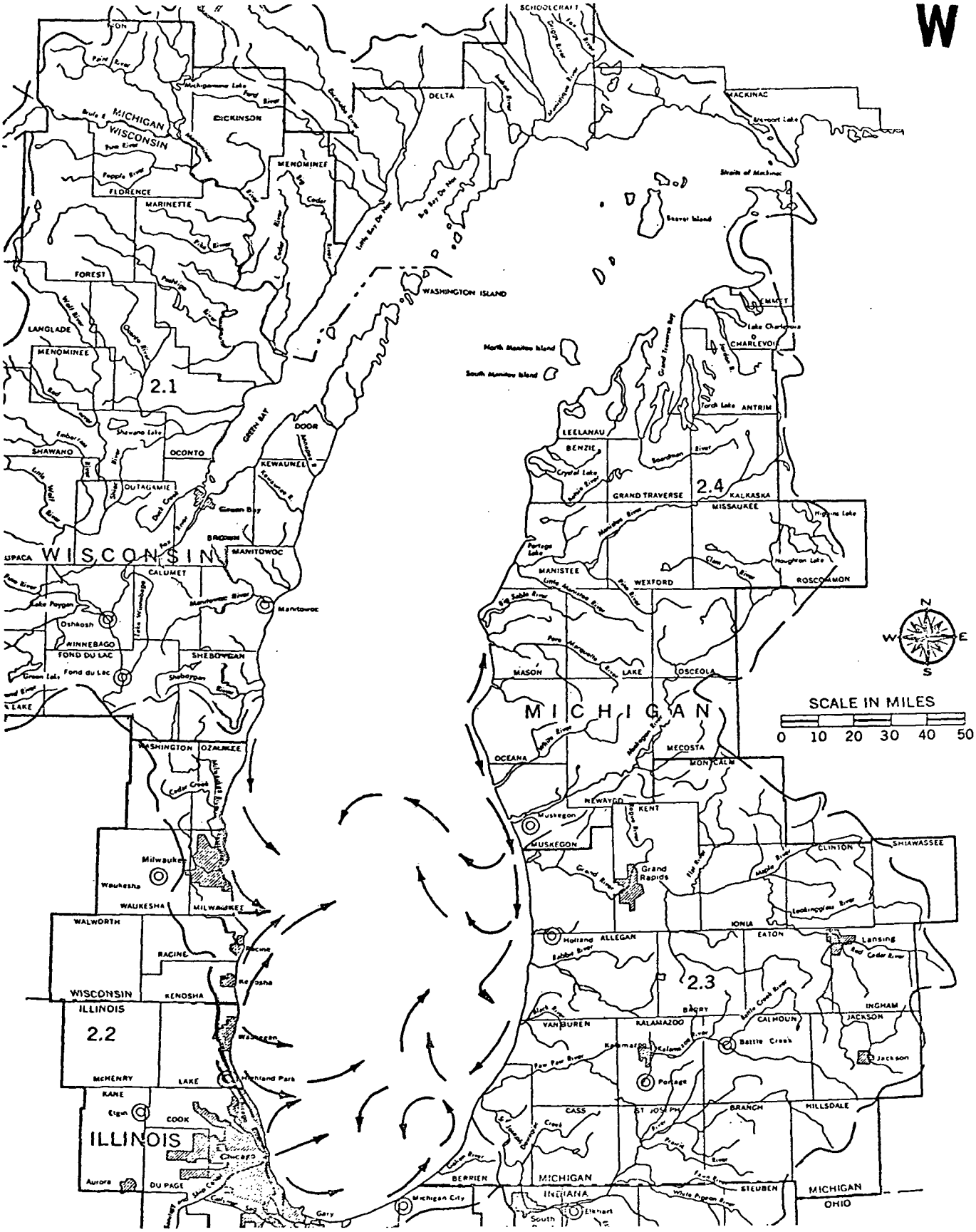


Figure 8. Surface current analysis as determined from turbidity patterns in LANDSAT-1 scenes. Weighted wind direction (Westerly) indicated in upper right-hand corner.

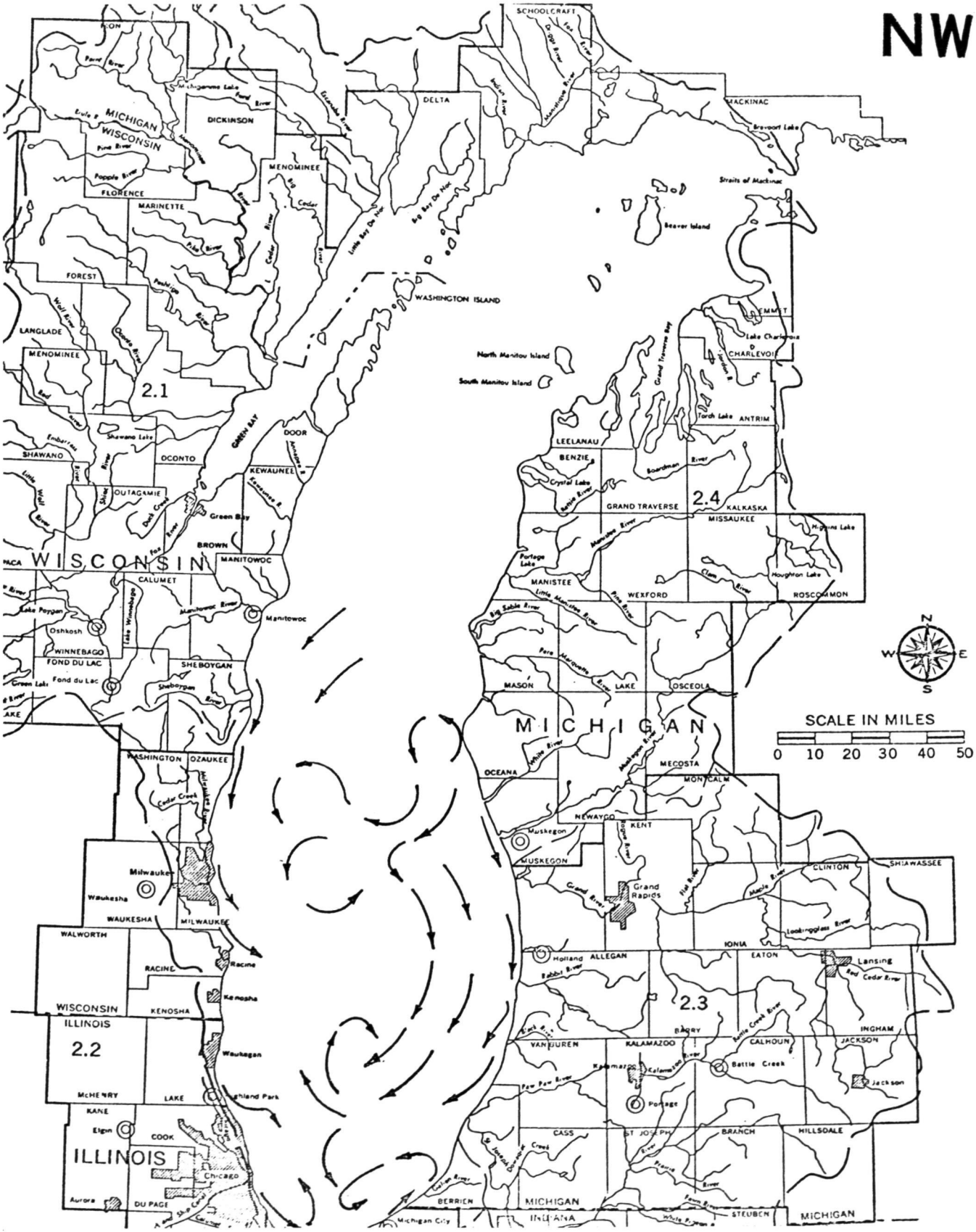


Figure 9. Surface current analysis as determined from turbidity patterns in LANDSAT-1 scenes. Weighted wind direction (Northwesterly) indicated in upper right-hand corner.

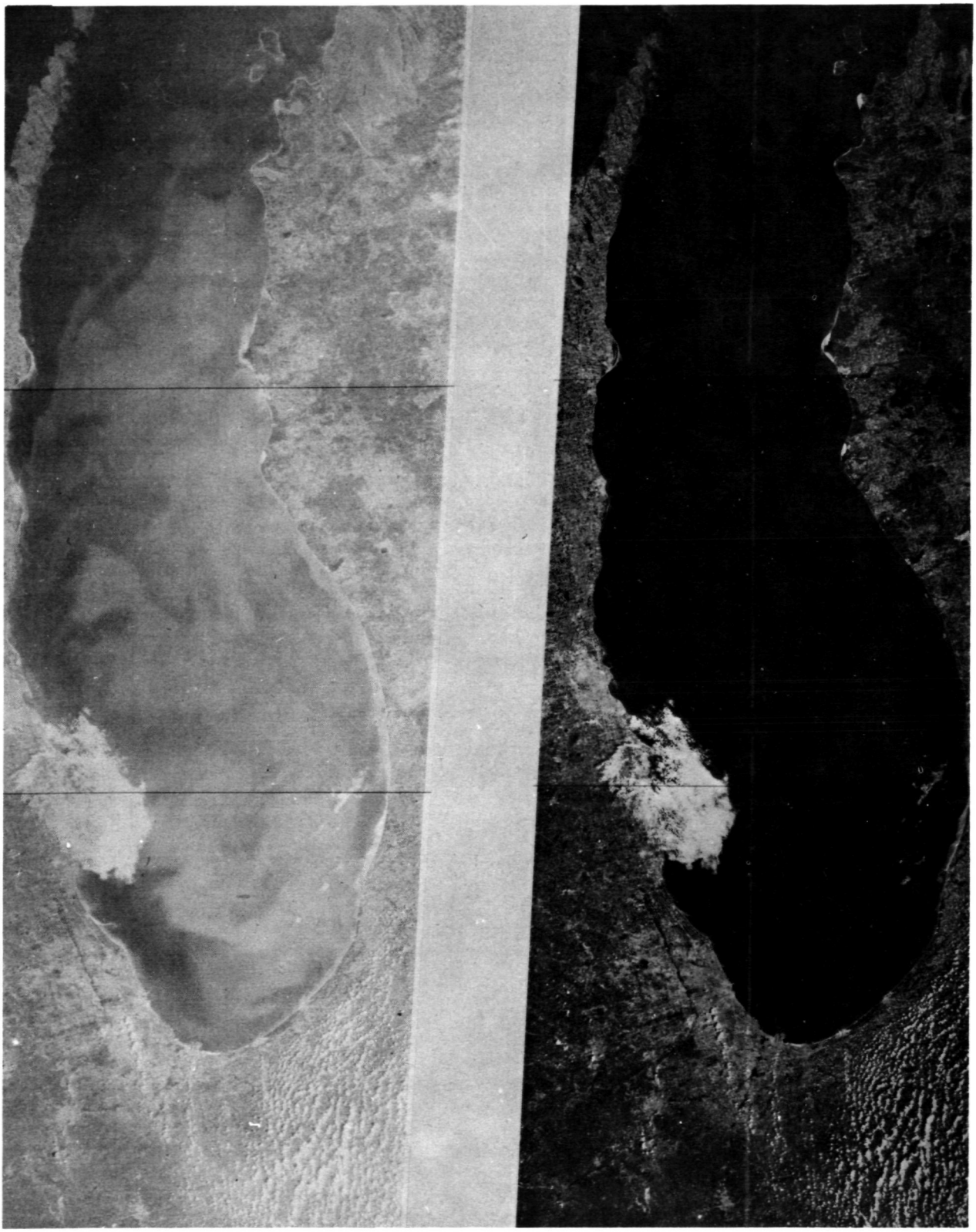


Figure 10. LANDSAT-1 images (MSS-4, left and MSS-5, right) obtained 3 August 1973, showing the extent of the calcium carbonate precipitation over southern Lake Michigan.

OCEAN COLOR IMAGERY - COASTAL ZONE COLOR SCANNER

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ABSTRACT

Investigations into the feasibility of sensing ocean color from high altitude for determination of chlorophyll and sediment distributions have been carried out using sensors on NASA aircraft, coordinated with surface measurements carried out by oceanographic vessels. Spectrometer measurements in 1971 and 1972 led to development of an imaging sensor now flying on a NASA U-2 and the Coastal Zone Color Scanner to fly on Nimbus G in 1978. Results of the U-2 effort have shown the imaging sensor to also be of great value in sensing pollutants in the ocean.

INTRODUCTION

In preparation for the flight of the Coastal Zone Color Scanner (CZCS) on Nimbus G in 1978, a breadboard scanner has been constructed for use on a U-2 aircraft. The scanner has ten spectral bands ranging from 433 to 772 nm center wavelength with spectral bandwidths from 20 to 27 nanometers. The gain of each channel was set, based on the 1972 CV 990 Ocean Color Expedition results, to be optimum for water as viewed from high altitude with the exception of one channel, at 733 nanometers, that has a gain like that of the LANDSAT MSS, optimized for land.

Provision has been made to adjust gains for time of day and seasonal sun angle effects and to offset the contribution of atmospheric backscatter to the signal. This allows the data collection system to be most efficiently used for recording the effects of ocean color without wasting dynamic range on the contribution of the atmosphere.

Flights began in April 1974 and have covered targets off the West Coast, lakes in California and Nevada, the Great Lakes, and the East Coast from the New York Bight to Florida and the Gulf of Mexico from Key West to Timbolier Bay.

The New York Bight has been of special interest because it provides an opportunity to study both the sediment plume of a major river and the effects of large-scale waste dumps going on continually in the Bight.

Data from the Bight, taken on a number of overflights, show the sediment plume in several parts of the tidal phase and a gap, possibly caused by a gyre, separating the plume from the dumping areas. Dispersion from the dump areas, seen on several occasions, shows a predominant movement to the Northeast and Southwest, toward Long Island and New Jersey, with little motion to seaward in the first few meters visible from the plane. This work has led to participation in an extensive program called MESA (Marine Ecosystems Analysis), a NOAA-led investigation of the New York Bight.

Investigations off Tampa, Florida were carried out, in cooperation with the State of Florida, to begin assessment of the ability of multispectral scanners to locate, identify and quantify so-called red tide blooms. Algae blooms, already fairly well developed, were easily detected and a

program involving laboratory, ship and U-2 movements set up to begin in the Fall of 1975.

Investigations off Sanibel Island, Tampa Bay and Panama City, Florida, and Timbolier Bay, Louisiana were carried out in November 1974 with surface truth measurements carried out by personnel from Moody College, Texas A&M University aboard the RV Calypso. These measurements are being compared with the surface truth measurements to determine gradient levels that can be detected and the quantitative accuracy that can be realized.

TECHNIQUES

The U-2 Ocean Color Scanner (OCS) senses simultaneously in ten spectral bands with a spatial resolution of 3.8 milliradians from an aircraft altitude of 19.8 km. Swath width is 20 nautical miles with a recording time of 2 hours available per flight on magnetic tape of the scanner output. The scanner is supported by four Mitchell-Vinten 70mm cameras that are normally loaded with black and white film in three of the cameras filtered for green, yellow and red and one camera loaded with SO 242 color film with an ultraviolet haze filter.

The OCS has ten spectral bands ranging from 433 to 772 nanometer center wavelength as shown in Table I. The radiance for saturation is shown in Table I for a gain of 1 for each channel. Gain may be increased separately for each channel in steps of 1.5, 2 and 3 to allow for changing sun angle due to seasonal changes or time of flight. All channels except 9 are optimized for water scenes, including atmospheric backscatter as seen from 19.8 km. Channel 9 has the same level of gain as the LANDSAT Band 6 that covers 700 to 800 nanometers.

TABLE I

PARAMETERS OF THE U-2 OCEAN COLOR SCANNER

Channel	Center Wavelength (nm)	Bandwidth (nm)	Radiance (Gain x 1) $mw/cm^2\mu$
1	433	22.5	40.1
2	471	21.5	26.0
3	509	27.5	23.6
4	547	24.5	14.7
5	583	25.0	11.8
6	620	26.0	10.0
7	662	22.0	7.55
8	698	20.5	5.0
9	733	22.5	11.9
10	772	23.0	3.47

All ten bands are recorded in the analog mode and, at this writing, any four bands selected are digitized and multiplexed on the aircraft together with time code. A new digitizer, now on order, will allow all ten channels to be digitized simultaneously on the aircraft. The data system is operated by the U-2 pilot by on-off switch and a reset button for the digitizer. Reset will not be required in the new system. Time of data

collection is usually determined from a flight plan prepared in advance although on some occasions the pilot has to exercise judgement such as when overflying an event such as a red tide that cannot be precisely located before flight.

Glint from the ocean surface is a serious problem that can obliterate any information about the content of the water below the surface. Early flights, in April 1974, showed that glint would appear in imagery, even in flights flown in the morning with relatively low sun angles. It was determined that glint could largely be avoided by flying before 10:30 a.m. and after 1:30 p.m., local sun time, and by flying directly toward or away from the sun whenever possible.

After flights, data is formatted and processed to tapes of calibrated radiance. When imagery is produced, an offset is applied to each channel to remove the DC background due to atmospheric backscatter. Black and white negatives are produced using a digital image processor and utilized to produce false color imagery. For analytical purposes, to develop algorithms, the data is reproduced as graphs of radiance along scan lines and grid print maps.

RESULTS

The first flights were conducted in April 1974 with tests from Wallops Flight Center. A flight was conducted on April 27 with one pass over the New York Bight on a due North-South line. The pass over the mouth of the Hudson clearly showed the Hudson River sediment plume and a waste dump with dispersion. The result, shown in Figure 1, is a false color image using the channels at 471, 583, and 662 nanometers.

The bright blue spot just south of Long Island is sun glint with ship wakes, one in the square pattern of a dump barge. Figure 2 shows three camera images from the color camera taken at 30-second intervals. The circular glint pattern, in the southeast corner of each image, varies in diameter due probably to varying surface roughness. Since the scanner lines run through the center of each image, from East to West, the glint pattern appears on scanner imagery only when the glint pattern extends to the North far enough to be seen by the scan line. Subsequent flights were flown directly toward and away from the sun, whenever possible, and at times of low solar elevation.

Since Nimbus G will fly in a high noon ascending mode orbit, a scan tilt mechanism is incorporated into the Coastal Zone Color Scanner to tilt the scan away from the sun glint in either hemisphere.

A flight conducted on July 22, 1974 utilized the flight line information garnered from the first flight and avoided glint entirely. This flight, conducted at very nearly the same time as the April flight, and hence at a higher solar elevation, again shows the Hudson plume and an acid waste dump in the Bight. This image, Figure 3, obtained at slack water on the high tide, shows considerable detail but more detail can be seen by further enhancement. Figure 4 is a color enhanced image obtained by multiplying the ratio of Channel 4 divided by Channel 5 times the ratio of Channel 7 divided by Channel 5.

In response to a request from the State of Florida, a program is being developed to determine the optical properties of the Gymnodinium breve

organism, known as "Red Tide" and to develop techniques for detecting algae blooms early in the event. This program will begin intensive effort in the summer of 1975 but some preliminary work was done in 1974 to familiarize personnel of the Department of Natural Resources of Florida with remote sensing techniques.

On September 9, 1974 a flight was flown conducted over the Tampa Bay area on the West Coast of Florida. No Gymnodinium breve was present but a concentration of the blue-green organism Oscillatoria erythrea was seen in the southwest corner of the image. Figure 5 shows the image, again made with enhanced data from Channels 2, 5, and 7. In addition to the algae bloom, sediments can be seen around the mouth of Tampa Bay, including a fan-shaped plume from Johns Pass, north of Tampa Bay.

Several flights have been conducted over the Chesapeake Bay in order to discriminate areas of high and low sediment concentration. In recent years, the clam population of the Chesapeake has been contaminated with bacterial levels so high that clamming was forbidden in many previously productive areas. In fact, in the summer of 1972, following Hurricane Agnes, all clamming was stopped in the Maryland portion of the Chesapeake.

Much of the pollution that enters the bay and is concentrated by clams comes from the Susquehanna River that drains large areas of Pennsylvania and New York before emptying into the Chesapeake. Bacteria laden particles enter the Bay and proceed toward the Atlantic but are subject to tidal motion, as well as river flow, as soon as they enter the Bay. It is desirable to determine sediment patterns as a guide to flow of material from the Susquehanna. Figure 6 shows a scanner image of the Upper Chesapeake Bay from the mouth of the Susquehanna to Gibson Island. The brighter areas are areas of high sediment concentration with anomalous areas of very low scattering, hence very little suspended particulate matter off the mouth of the Chester River and Bodkin Creek. These studies will be continued as often as possible to build up a base of experience on sediment motion in the Chesapeake.

In November 1974, an opportunity arose to conduct investigations in conjunction with surface truth measurements being carried out, in the Gulf of Mexico, by personnel from Texas A & M University aboard the RV Calypso. The Calypso was available for about one week to carry out investigations along the Gulf Coast from Key West, Florida to the Timbolier Bay area in Louisiana.

In cooperation with the Texas A & M personnel, a sampling plan was devised to provide coverage of a reasonably large area in a short period of time. A track was selected in the direction of the proposed aircraft flight and ten nautical miles long. The Calypso carried out extensive sampling at stations at the beginning and end of the ten-mile track and at the midpoint. Small, inflatable outboard boats were deployed on either side of the larger vessel collecting samples and making measurements at 1-mile intervals four miles out on either side of the larger vessel. The small boats were tracked by radar to verify location and each collected samples at 12 locations as shown in Figure 7. In this manner, an 80-square mile area was sampled in about 4 hours.

The large vessel track, A to B to C, is parallel to the aircraft flight line and the small craft tracks perpendicular to the flight path but parallel to the sensor scan line direction. This allows fairly easy comparison by selecting one scan line that falls along a set of readings. Figure 8 shows

the radiance values for four spectral channels (2, 4, 5 and 7) along a position centered on 29°32'N, 85°28'W in the Gulf of Mexico off Panama City, Florida. Also shown are the chlorophyll measurements at the surface for each sampling point.

A preliminary algorithm has been applied to some of the measurements using two channels at a time. Using only two channels, Channels 4 and 7 appear the best in a formula where

$$\frac{R_7}{R_4} = a + b \log_e C$$

where R_4 = radiance (unenhanced) 547 nm

R_7 = radiance (unenhanced) 662 nm

a = 0.309

b = .0166

C = chlorophyll Mg/M^3

A comparison along the track is shown in Figure 9. The algorithm was next applied to the scene to produce the image shown in Figure 10. This is the first attempt at applying an algorithm to imagery and will be further refined to utilize more than one channel.

CONCLUSIONS

A scanner with spectral channels and dynamic range optimized for ocean color can detect subtle color changes even through the earth's atmosphere. If the sensor has a reasonably high signal-to-noise ratio, much of the atmospheric backscatter can be eliminated by subtracting a DC offset from the total signal and preserving the modulation caused by color changes in the ocean. Quantification of parameters such as chlorophyll concentration, on a global scale, will require extensive research effort, prior to the launch of the Nimbus G CZCS, to include high altitude aircraft scanner flights coordinated with far more extensive surface truth measurements than have been accomplished to date.

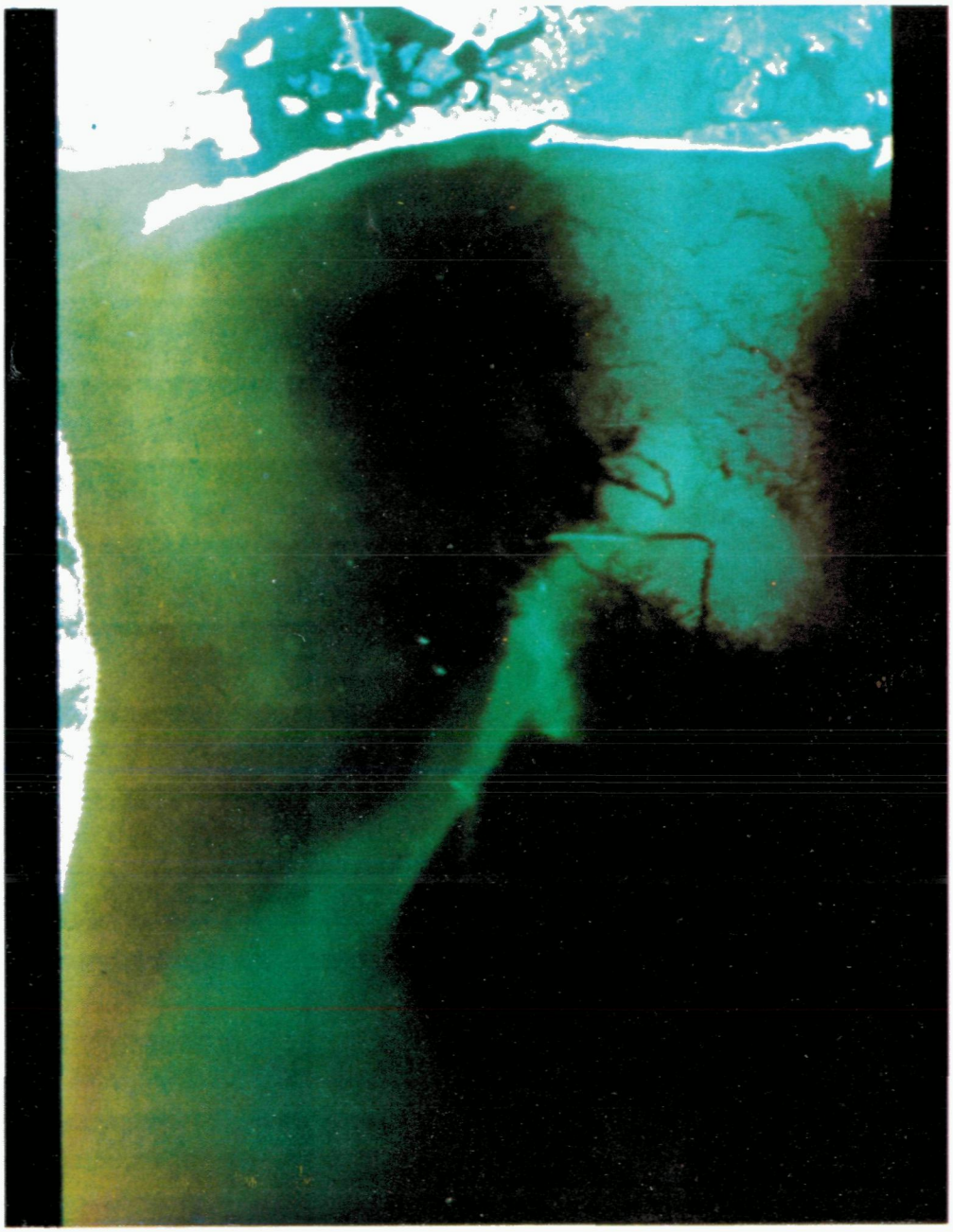


FIGURE 1

False Color Image, New York Bight, April 27, 1974
showing Sediment Plume, Waste Dump, Sun Glint



FIGURE 2

Color Photographs of New York Bight
showing Glint Patterns



FIGURE 3

False Color Image, New York Bight, July 22, 1974
showing Hudson River Plume, Acid Waste Dump

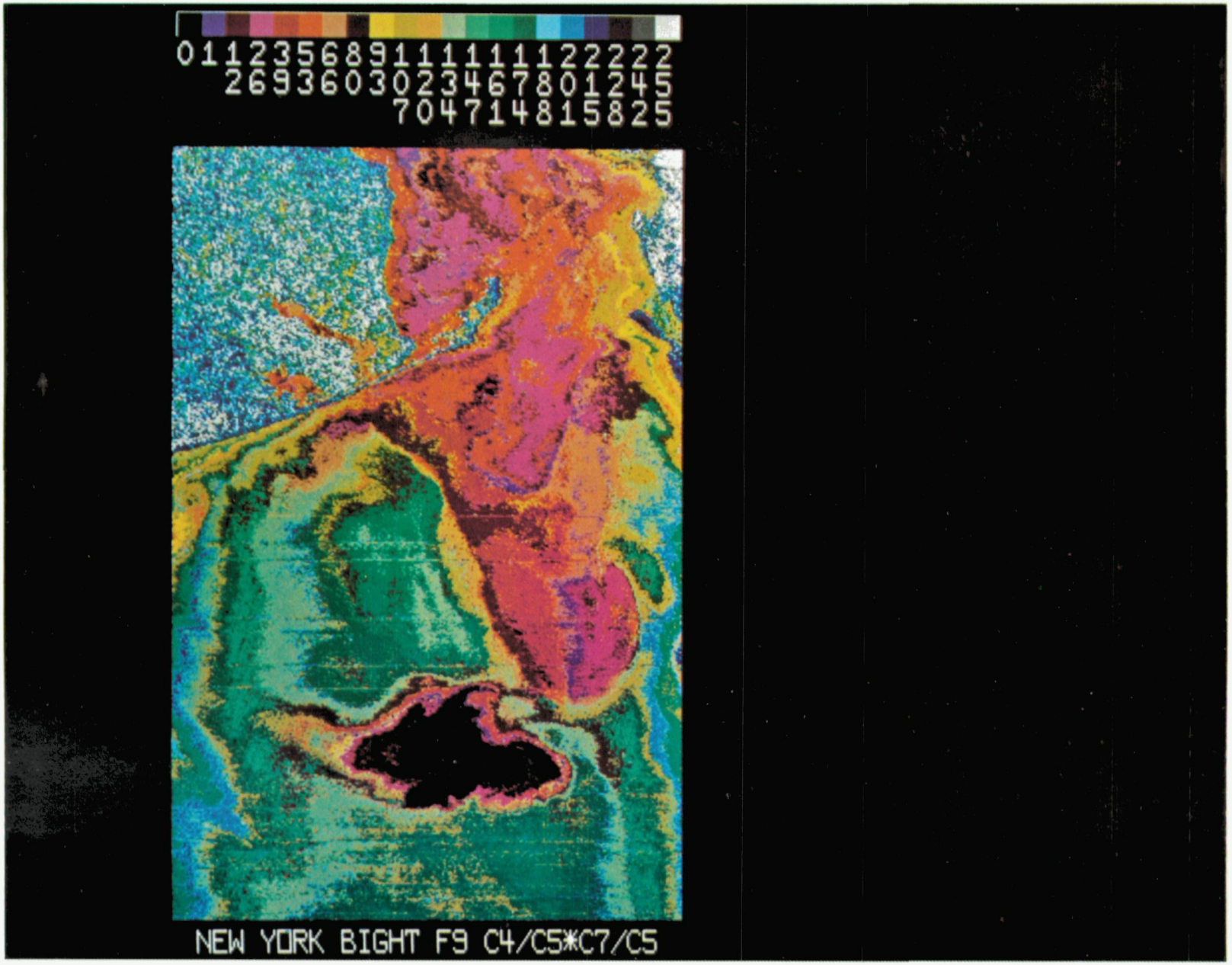


FIGURE 4

Enhanced Color Image of Figure 3
showing Detail of Hudson River Plume

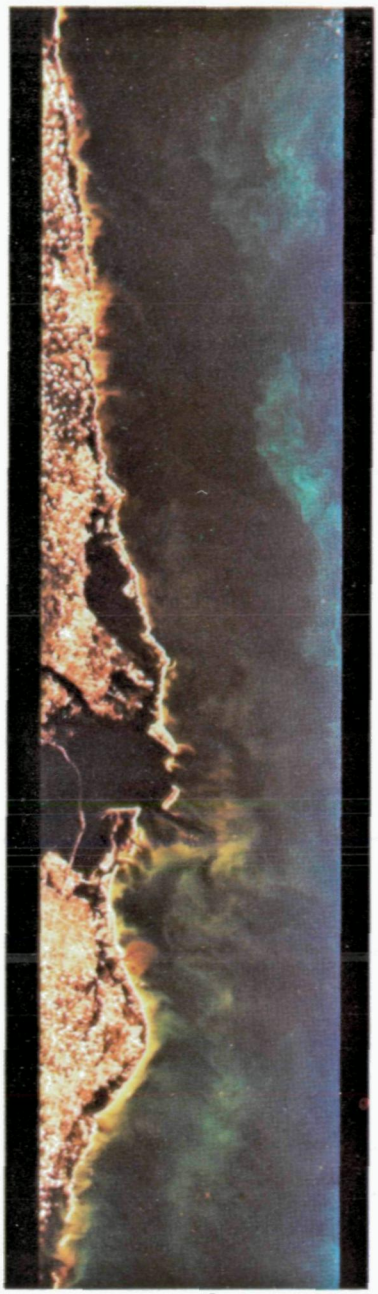


FIGURE 5

False Color Image of Tampa Bay Area, Sept. 9, 1974
Dredge Spoil from Johns Pass, Oscillatoria Erythrea

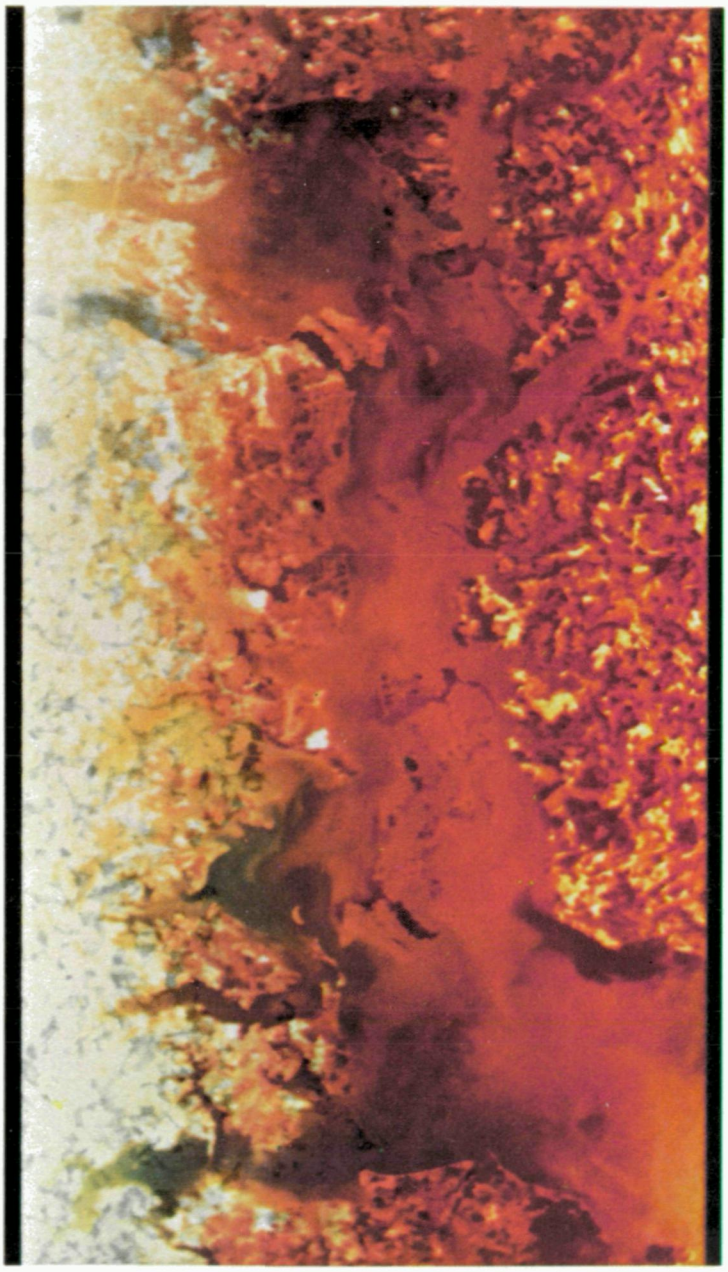
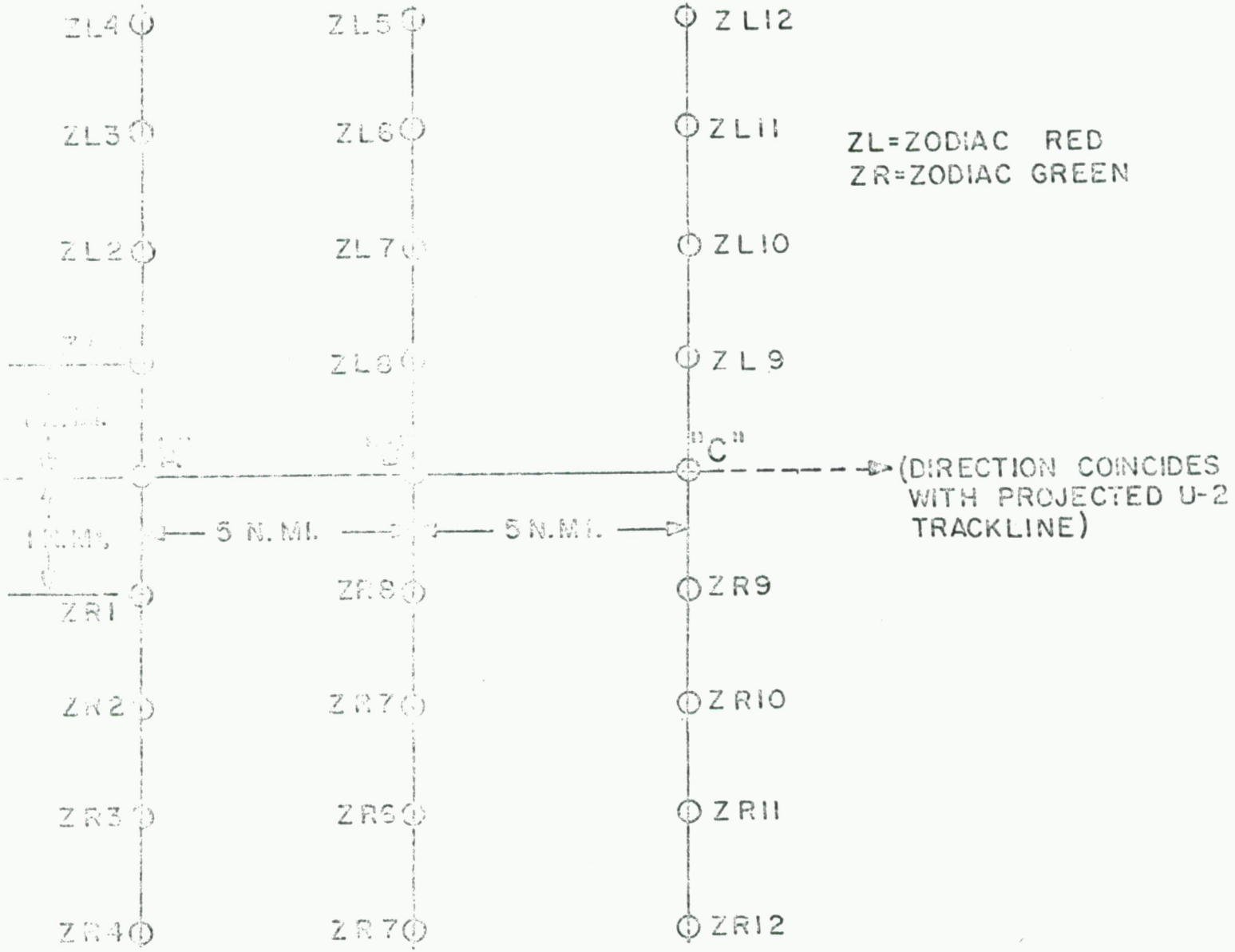


FIGURE 6

False Color Image, Upper Chesapeake Bay, April 27, 1974
Sediment Pattern, Susquehanna River Inflow



GROUND TRUTH- SAMPLING GRID

FIGURE 7

2000

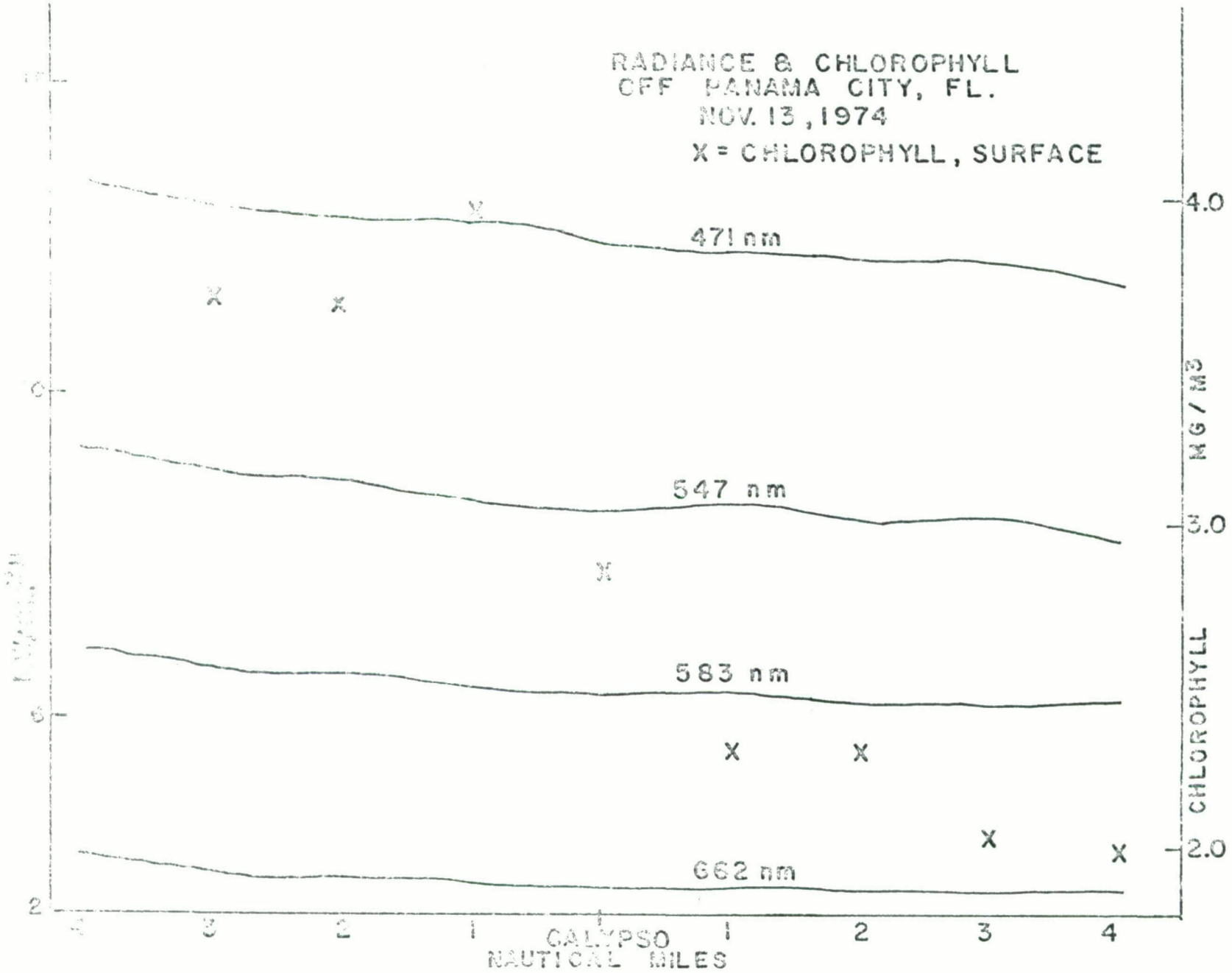

RADIANCE & CHLOROPHYLL
OFF PANAMA CITY, FL.
NOV. 13, 1974
X = CHLOROPHYLL, SURFACE
471 nm
547 nm
583 nm
662 nm
4.0
3.0
2.0
MG / M3
CHLOROPHYLL
CALYPSO
NAUTICAL MILES
3
2
1
1
2
3
4

FIGURE 8

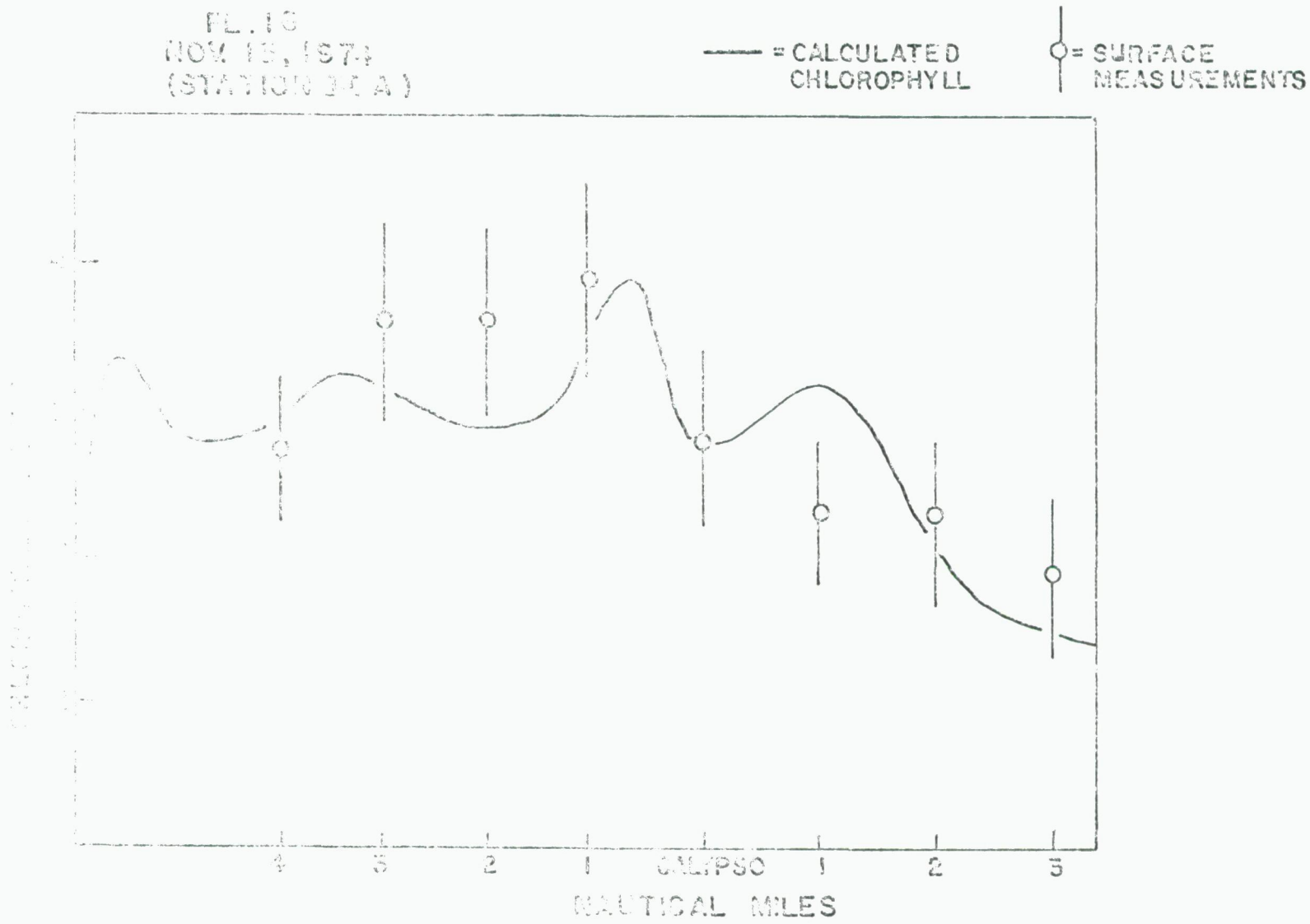


FIGURE 9
Calculated vs Measured Chlorophyll
Off Panama City, Florida



FIGURE 10

Algorithm Enhanced Image of Chlorophyll
Off Panama City, Florida

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SKYLAB INVESTIGATION OF THE UPWELLING OFF THE NORTHWEST COAST OF AFRICA M-7

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ABSTRACT

The upwelling off the NW coast of Africa in the vicinity of Cape Blanc was studied in February – March 1974 from aircraft and in September 1973 from Skylab. The aircraft study was designed to determine the effectiveness of a differential radiometer in quantifying surface chlorophyll concentrations. Photographic images of the S190A Multispectral Camera and the S190B Earth Terrain Camera from Skylab were used to study distributional patterns of suspended material and to locate ocean color boundaries. The thermal channel of the S192 Multispectral Scanner was used to map sea-surface temperature distributions offshore of Cape Blanc. Correlating ocean color changes with temperature gradients is an effective method of qualitatively estimating biological productivity in the upwelling region off Africa.

INTRODUCTION

From a practical standpoint, phytoplankton is a very important life form in the ocean, since primary productivity can be directly related to potential production of commercial fish. In upwelling regions of the world, such as off the Northwest coast of Africa, wind stress produces an offshore movement of surface waters which are replaced by cooler, nutrient-rich subsurface waters. These upwelled waters are an excellent medium for the propagation of phytoplankton. Though upwelling regions comprise only about one-tenth of 1 percent of the ocean surface, Ryther (1969) estimates that they produce about half of the world's fish supply.

When studying plankton over large areas of the ocean, oceanographers face serious logistics problems. Since it may take several days to several weeks to cover a large study area by ship, the best that can be hoped for is a time-averaged picture of plankton distributions. The ship sampling program may miss patches of plankton of significant interest and the concentrations may be changing rapidly over time. Since large surface areas of the ocean can be easily seen from space, the possibility of synoptically determining plankton quantities and distributions from earth orbit is extremely attractive.

On 4 September 1973, the Skylab spacecraft passed directly over the Cape Blanc section of NW Africa. This report will summarize the interpretation to date of radiometeric data derived from Skylab as it pertains to plankton distributions off the African coast.

ATMOSPHERIC CONDITIONS

The NW coast of Africa can be effectively studied from space, since favorable meteorological conditions are present throughout most of the year. During winter in the Northern Hemisphere, a high pressure system is centered between the Canary Islands and the Azores. In summer, this system extends further to the north and west. Therefore, the coast of Africa experiences clear weather during most of the year with extremely good horizontal and vertical visibility.

The NE trade winds are responsible for the upwelling conditions off the NW African coast. During the summer months when the Trades are located between 15°N and 35°N latitude, the principal component of the winds is northerly, therefore giving rise to the most intense upwelling conditions. (Szekielda, 1973).

Figure 1 shows a Nimbus 5 thermal image of the NW coast of Africa taken 2 September 1973, 2 days prior to the Skylab overpass. The clear conditions surrounding Cape Blanc indicate the influence of the offshore anticyclone and the low-moisture NE trade winds. The band of thick clouds to the south represents the Intertropical Convergence Zone.

SPECTRAL PROPERTIES OF PLANKTON

Light penetration in water is affected by plankton, algae, and dissolved and suspended matter. As a result, the composition of backscattered light from below the air-sea interface is determined by the nature of the constituents in the water column. In contrast to the absorption spectrum of chemically-pure chlorophyll in solution, algae suspensions absorb and scatter light more uniformly throughout the visible part of the electromagnetic spectrum. Because of the spectral absorption and scattering properties of plankton, its concentration can be estimated by measuring the spectral backscattered radiance over water.

When monitoring plankton or biomass from high altitudes, we must consider the fact that algae behave more like a suspension than a pure solution of chlorophyll. As a result, solar light will be scattered at the outer shell of the plankton organisms. The absorption of incident irradiance by the cells depends on their outer structure and the optical density inside the cell. Variation in the optical density or the configuration of the cells may change the intensity of backscattered light even if the incident solar irradiance, sun angle, and chlorophyll concentration per unit of volume remain constant. Yentsch (1960) found that the red absorption band of chlorophyll has little influence on water color. This means that the signal obtained with a red band sensor would record primarily the effect of backscattered light from the organisms.

The intensity of backscattered light caused by plankton and dissolved matter from the ocean as a function of wavelength is given in Figure 2. Gulf Stream water was used as a reference water assuming that the chlorophyll concentration of less than 0.02 $\mu g \cdot l^{-1}$ does not change significantly the backscattered light compared to pure water. It was assumed, for the interpretation of the different spectra, that sky conditions, sun angle, and sea state were the same over both sites. The spectrum in Figure 2 is the difference in energy between the spectrum obtained in near-coastal water and the spectrum recorded over the Gulf Stream.

If both water masses had the same optical characteristics and oceanic conditions, the energy difference in both spectra should be equal to zero. Any differences between the two signals would thus be caused by dissolved and/or particulate matter in the sea. If chlorophyll affected the backscattered light by its absorption properties in the shorter wavelengths, we would expect differences near the absorption bands of chlorophyll.

Chlorophylls have two main absorption maxima in the visible region of the electromagnetic spectrum. The main absorption peaks for pure chlorphyll *a* are at 0.446 μm and 0.663 μm. However, the naturally occurring chlorophyll *a* types in plants have spectra with peaks near 0.673 and 0.683 μm. Other forms show maxima near 0.690 and 0.710 μm.

The spectrum in Figure 2 shows that the first and the second absorption bands of chlorophyll have only a minor influence on the total backscattered light. Strong absorption appears at about 0.72 μm, but

the maximum of backscattered light appears at 0.58 μm. Considering only the portion between the second absorption band and the near-infrared, it can be seen that only a linear decrease of backscattered light appears. This is an indication that in addition to the absorption of light by chlorophyll, backscattered light from the organisms themselves contributes to the total backscattered energy. Thus, the size and concentration of particles or marine organisms seem to be the important contributors to the changes in backscattered light intensity as measured in the Skylab sensors. The scattering intensity of suspended particles is proportional to λ^{-n} where λ is the wavelength and n the Rayleigh value which may vary from 4 for pure water to 0 at high turbidity. In other words, the intensity of backscattered light increases with particle concentration. This shows the important influence of particles without chlorophyll on the backscattered light from below the sea surface. Lorenzen (1970) established a correlation between surface chlorophyll concentrations and primary productivity for different oceanic waters. Better correlations were found when chlorophyll and primary productivity data from the upwelling region off the NW coast of Africa were compared. This suggests that a significant relationship between the two parameters can be obtained when individual oceanic regions are studied, thus making surface chlorophyll measurements that much more valuable.

An often suggested algorithm of narrow band ocean color reflectances was employed in an aircraft mission for evaluation of its effectiveness in chlorophyll determination and in recognition of changes in regional ocean color distributions. A ratio of the 0.443 μm to the 0.525 μm reflectances has been discussed by Clarke and Ewing (1974) and Duntley (1972) as having the ability to determine chlorophyll concentration in near-surface waters from aircraft and satellite altitudes. From these observations Arvesen et. al. (1973) developed a differential correlation radiometric method to detect chlorophyll. Their measurements of ratio values using the continuous recording differential radiometer, correlated well with real-time sea-truth measurements of surface chlorophyll concentrations. From the results of flights over various types of water masses, a calibration of the reflectance ratio to surface chlorophyll concentrations (mg/m^3) was constructed.

During February and March 1974 the differential radiometric (DR) method was used in extensive oceanographic aircraft missions as part of the JOINT-I project in a 1 square degree region (20° - 21°N. latitude x 17° - 18° W. longitude) offshore of Cape Blanc. In comparison with surface chlorophyll sea-truth, the DR method was not effective in the determination of chlorophyll off Africa. Interferences caused by suspended particulates of eolian origin in the surface waters plus presumed concentrations of Gelbstoff, resulted in an "enhanced" apparent chlorophyll signal. These interferences can be explained by the following: 1) Increased backscattered radiance was caused by the high concentration of high refractive index (highly reflective) eolian and wave eroded particulates; 2) Inherent optical properties including absorption by dissolved Gelbstoff, attenuation of radiance by sea water and particulate scattering (including multiple scattering) produced a spectral signal that the ratio method could not differentiate from that of chlorophyll; 3) Selective scattering by phytoplankton and high non-selective scattering by the additional particulates in multiple events produced an increased backscattered signal to the DR which was as "enhanced" chlorophyll signature. These apparent chlorophyll signals were investigated in laboratory studies and were found to be principally attributed to the scattering properties of both inorganic particles and algae in suspension.

Although this color ratio did not effectively determine chlorophyll levels, there was a strong correlation between sea surface temperature (SST) gradients and the observed ocean color ratio gradients. Higher ratios were coincident with low temperature, with only a few nearshore exceptions. A significant correlation of this color ratio and *total* particulates from sea-truth measurements does exist and, in addition, increased fishing was observed to be closely associated with the SST-DR ratio gradients (Tabor 1975). Therefore ocean color changes associated with sea-surface temperature gradients are indicative of productive water masses off the NW coast of Africa.

CAPE BLANC

The hydrography between Cape Blanc and Cape Timiris can be described by the T-S diagram based on 16 stations (Allain [1970]) where data were collected between 0 and 800 m. Two main formations of water masses can be recognized. The first is within the upper 300 m and can be considered a mixture of surface water and Central South Atlantic water with values of 12°C and 35.35°/oo at 300 m. The layer between 400 and 800 m consists mainly of Central North Atlantic water with temperatures between 12 and 8°C. The influence of Antarctic Intermediate Water is shown by water with a salinity of 35.05°/oo and a temperature of 7°C. Upwelling in this area is limited for water types with temperatures between 18.5°C and 20.5°C and salinities between 35.8 and 35.95°/oo, which show that the upwelling has its origin in the upper 100 m.

The upwelling in the vicinity of Cape Blanc is persistent throughout most of the year and is evident by the high concentrations of chlorophyll noted in Figures 3 and 4. A survey of fish tonnages between Cape Blanc and Cape Timiris was made by Boley (1974) in July of 1973. High concentrations of fish were observed west of Cape Blanc while very high tonnages were noted near Cape Timiris. The tonnages of fish therefore, show some correlation with surface chlorophyll concentrations in this area.

During the 4 September 1973 overpass, Skylab collected radiometric data with the S190A Multispectral Camera, the S190B Earth Terrain Camera and the S192 Multispectral Scanner. The ground coverage provided by these sensors is shown in Figure 5. During the subsequent Skylab 4 mission, photographs were also taken of the study area with hand-held cameras.

Figure 6 is a high resolution color photograph of the Banc d'Arguin taken with S190B Earth Terrain Camera. The scale of the photograph is approximately 1 : 900,00 in covering an area of 110 x 110 Km. There is an obvious color gradient of blue to green from offshore to nearshore waters indicative of the presence of suspended material and Gelbstoff. Figure 7 is the green band S190A multispectral camera image having a response region between 0.5 and 0.6 μm. The scale of this photograph is roughly 1 : 2.7 million covering an area of 157 x 157 Km. The patterns and patchiness of offshore suspended material are evident from this photograph.

The nearshore patterns of suspended material indicate a northerly flow of waters toward Cape Blanc. The "U-shaped" plankton patch southwest of the Cape, indicates a southerly drift of waters from north of the Cape. Using dynamic topography, Fedoseev (1970) discussed the geostrophic circulation of surface waters in the shelf region and concluded that quasi-stationary gyres are formed in the eastern boundary of the Canary Current. The most stationary gyre south of Cape Blanc was observed throughout the year and the offshore patterns noted in the Skylab images are influenced by the flow of the gyre.

Szekielda (1974) reports that plankton patchiness varies especially with the change of seasons. A strong gradient of chlorophyll and/or plankton offshore of Cape Timiris is connected with the converging water masses from the Banc d'Arguin and has been detected in all four seasons. Figure 8 shows the location of offshore ocean color boundaries as derived from LANDSAT-1 and Skylab. The southern gradients show seasonal positions between 1972 and 1974. Besides small-scale fluctuations, the gradient shifts over a maximum distance of only about 16 Km. This is an indication that the offshore gradient is a fairly permanent feature.

The enclosed lines south of Cape Blanc, are the relative positions of the "U-shaped" suspended material patch observed from Skylab 3 and 4. Between September 1973 and January 1974, the patch experienced a broadening and shoreward movement. This may be a result of a seasonal change in the circulation.

Channel 13, of the multiscanner scanner of Skylab, recorded emitted thermal radiation from the surface of the earth. For the Cape Blanc overpass, the radiation data were converted to blackbody temperatures and a histogram was generated by the Johnson Space Center as shown in Figure 9. Classifications were chosen and a color-coded image was produced corresponding to different temperature intervals. Figure 10 is a color-coded temperature map of the waters offshore of Cape Blanc. The temperatures have not been corrected for atmospheric effects, however, the relative temperature gradients can be used to locate the origin of upwelled waters. The cold patch of water in Figure 10 is shown to be roughly between 7 and 11°C. Coldest known upwelling water off the African coast has only been reported to be as low as 14°C. Therefore it is estimated that the calculated blackbody temperatures are at least 4 to 6°C colder than actually present. Since the cold patch directly corresponds to the "U-shaped" suspended material pattern observed in the imagery, this is undoubtedly a source of upwelled water. In September of 1972, Dr. Ballester (Szekielda, 1974) observed a strong gradient of temperatures and fluorescence to the southwest of Cape Blanc. The temperature distribution is shown in Figure 11. The temperature gradient offshore of Cape Blanc is located in the same area as the cold patch we observed from Skylab.

As described previously, ocean color changes associated with sea surface temperature gradients indicate productive water masses in this region. The Skylab spacecraft was effective in recording these gradients and it can therefore be determined that an intensive area of upwelling was present in September of 1973. By correlating the observed ocean color changes with the low temperature readings, an obvious area of productive waters was apparent offshore of Cape Blanc.

CONCLUSIONS

The spectral properties of the upwelled waters off the NW coast of Africa have been studied with observations derived from aircraft and Skylab. Results of the aircraft study indicate that the two-channel, ratio approach is ineffective in determining surface chlorophyll concentrations and should not be used in future studies. Ocean color boundaries and temperature gradients were found to be directly correlated with each other and also with fishing effort in the upwelling region. Photographic and scanner data derived from Skylab has been effective in locating ocean color boundaries and mapping temperature distributions. Both can be utilized in this region to qualitatively determine areas of biological productivity. This simple correlation may be applicable in future efforts toward fishery resource management in upwelling areas.

ACKNOWLEDGMENTS

Portions of this research were sponsored by NASA under Contract No. NAS9-13344. We would like to acknowledge the assistance provided by the University of Washington during the JOINT-I project from February through March 1974.

REFERENCES

Allain, C. (1970). Les conditions hydrologiques sur la bordure Atlantique de l'Afrique du nord-ouest. Rapp. P. v. Cons. Explor. Mer. 159, 25.

Arvesen, J. C., Millard, J. P. and Weaver, E. C. (1973). Remote Sensing of Chlorophyll and Temperature in Marine and Fresh Waters. Astronautica Acta. Vol. 18, 229-239.

Boley, M.T. (1974). Compte-Rendu De La Mission Tassergal, Cap 73-11, 9 au 23 Juillet 1973. CINECA Newsletter, Int. Council for the Expl. of the Sea, Charlottenlund Castle, Denmark. 62-67.

Clarke, G. L. and Ewing, G. C. (1974). Remote Spectroscopy of the Sea for Biological Production Studies. *In* Optical Aspects of Oceanography, Julva, N. G. and E. Steeman Nielsen, eds. Academic Press, New York, N. Y. 389-412.

Duntley, S. Q. (1972). Detection of Ocean Chlorophyll from Earth Orbit. 4th Annual Earth Res. Program Review, Vol. IV, NOAA and NRL Programs, January 17-21, 1972. NASA, Manned Spacecraft Center, Houston, Texas, 1-25.

Fedoseev, A. (1970). Geostrophic Circulation of Surface Waters on the Shelf of North-West Africa. Rapp. P.-v. Cons. Explor. Mer. 159, 32-37.

Lorenzen, C. J. (1970). Surface chlorophyll as an index of the depth, chlorophyll content, and primary productivity of the euphotic layer. Limnol. & Oceanogr. 15, 479-480.

Ryther, J. H. (1969). Photosynthesis and Fish Production in the Sea. Science, Vol. 166, No. 3901, 72-76.

Szekielda, K-H. (1973). Distribution Pattern of Temperature and Biomass in the Upwelling Area Along the NW Coast of Africa. ASP Fall Conv., Lake Buena Vista, Fla. 664-716.

Szekielda, K-H. (1974). Observations of Suspended Material from Spacecraft Altitudes. Deutsche Hydrographische Zeitschrift, Jahrgang 27, 1974, Heft 4, 159-170.

Tabor, P. (1975). Evaluation of Chlorophyll Measurements by Differential Radiometry from Aircraft Altitudes. Master's Thesis, College of Marine Studies, University of Delaware, 194 p.

Yentsch, C. S. (1960). The Influence of Phytoplankton Pigments on the Color of Seawater. Deep-Sea Res. 7, 1-9.

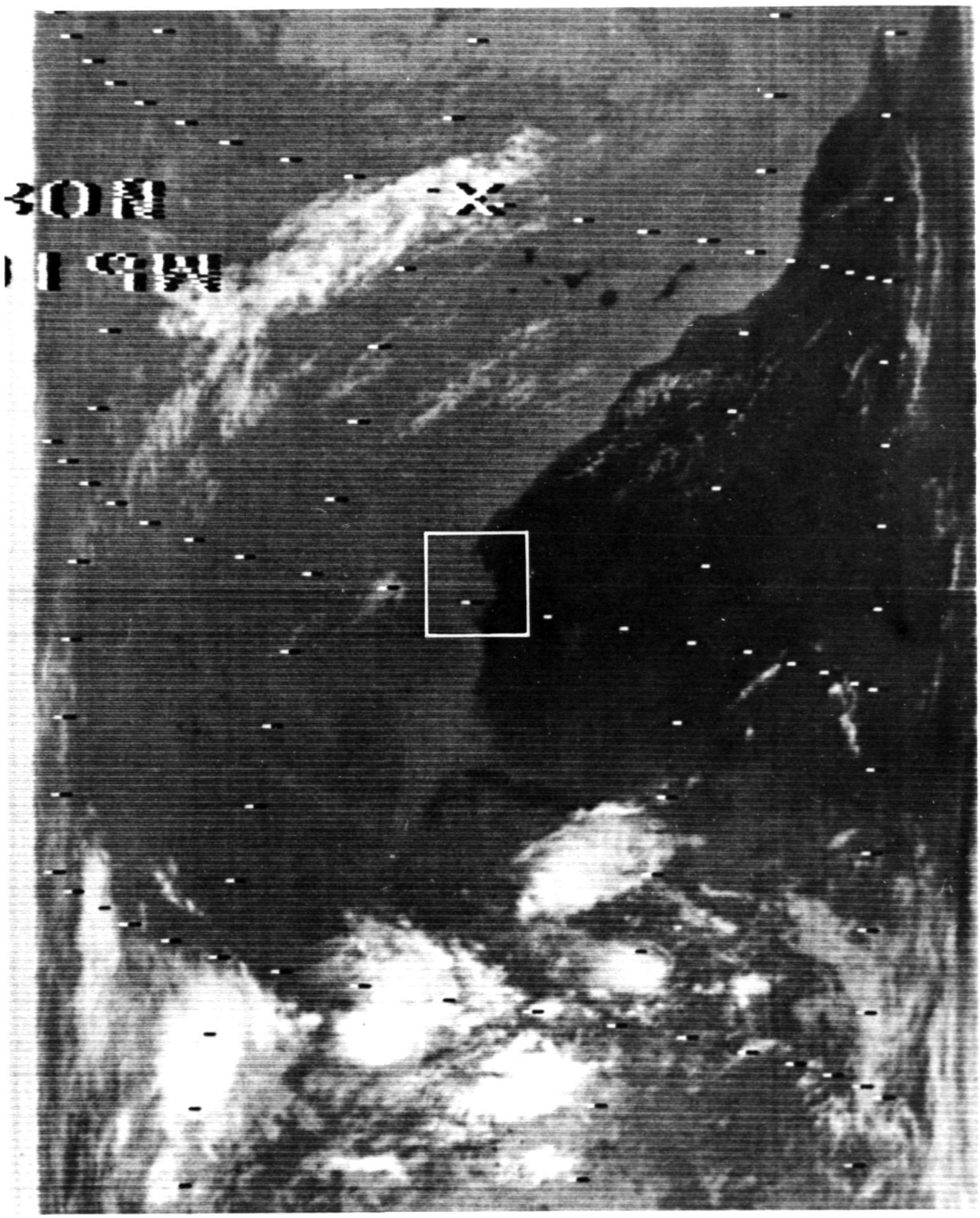


Figure 1. Nimbus 5 thermal image of the NW coast of Africa taken 2 September 1973. Cape Blanc is located within the enclosure.

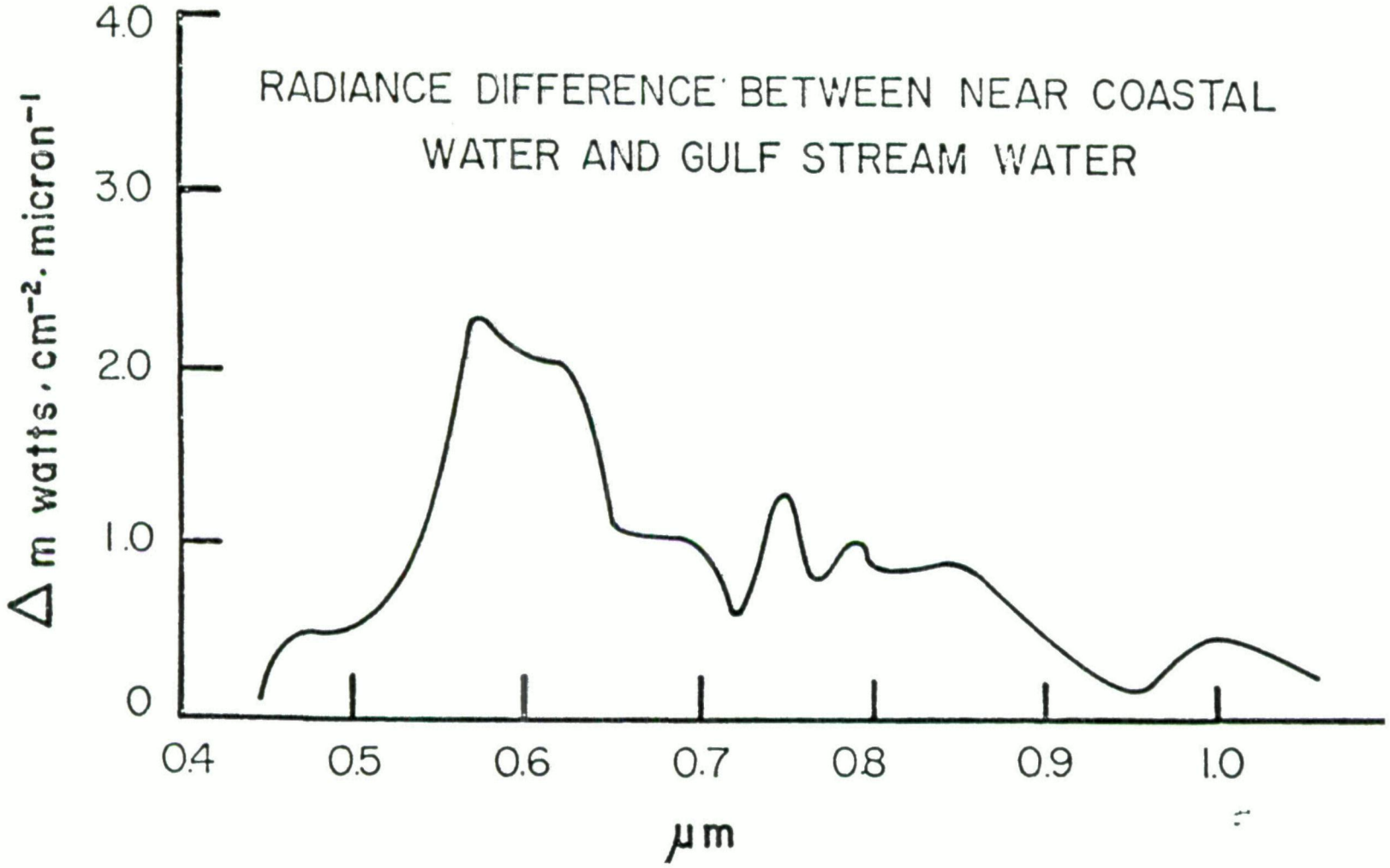


Figure 2. Wavelength dependent radiance caused by particulate and dissolved matter. (from Szekielda (1974)).

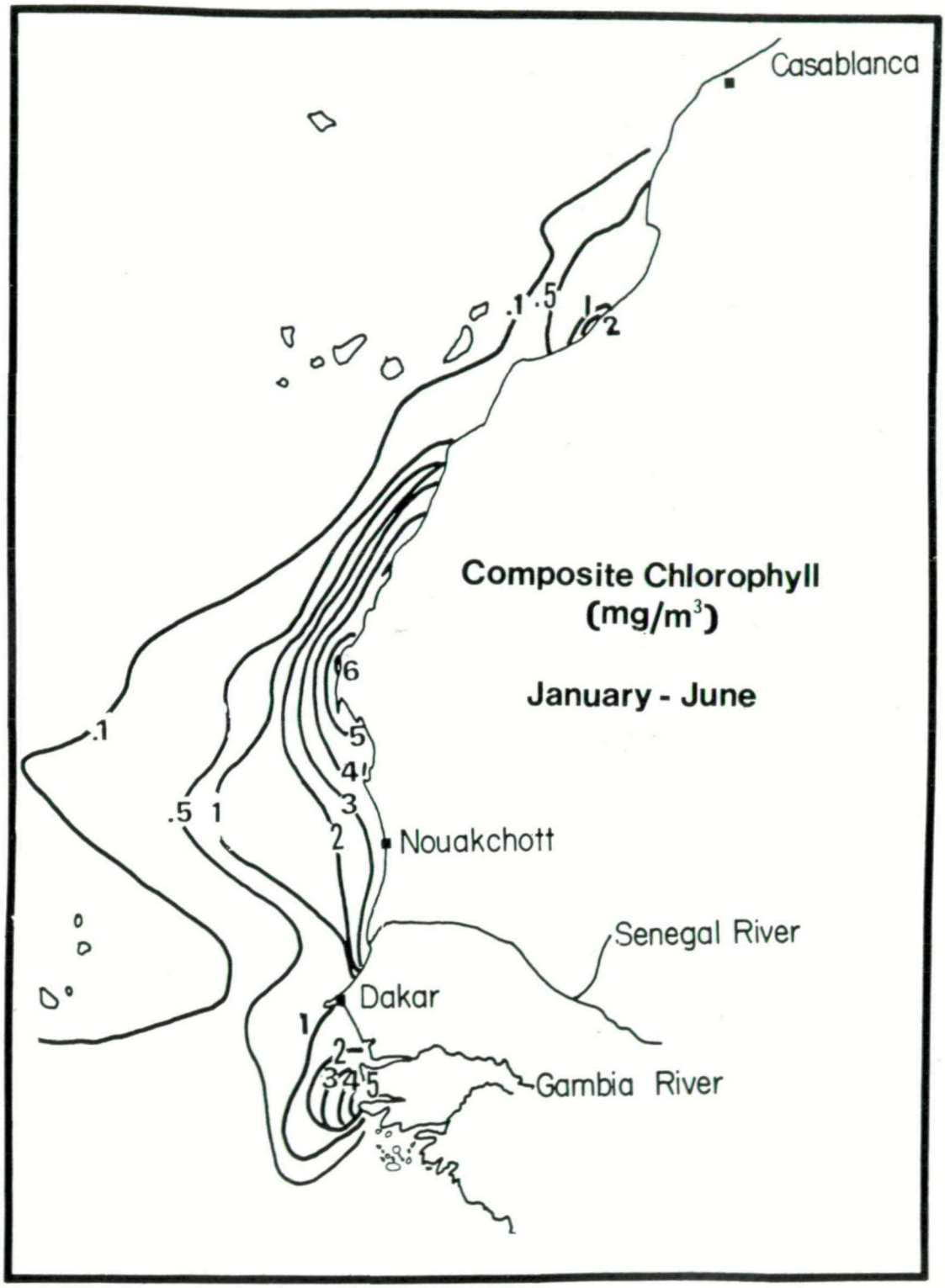


Figure 3. Composite of chlorophyll concentrations for the months January – June.

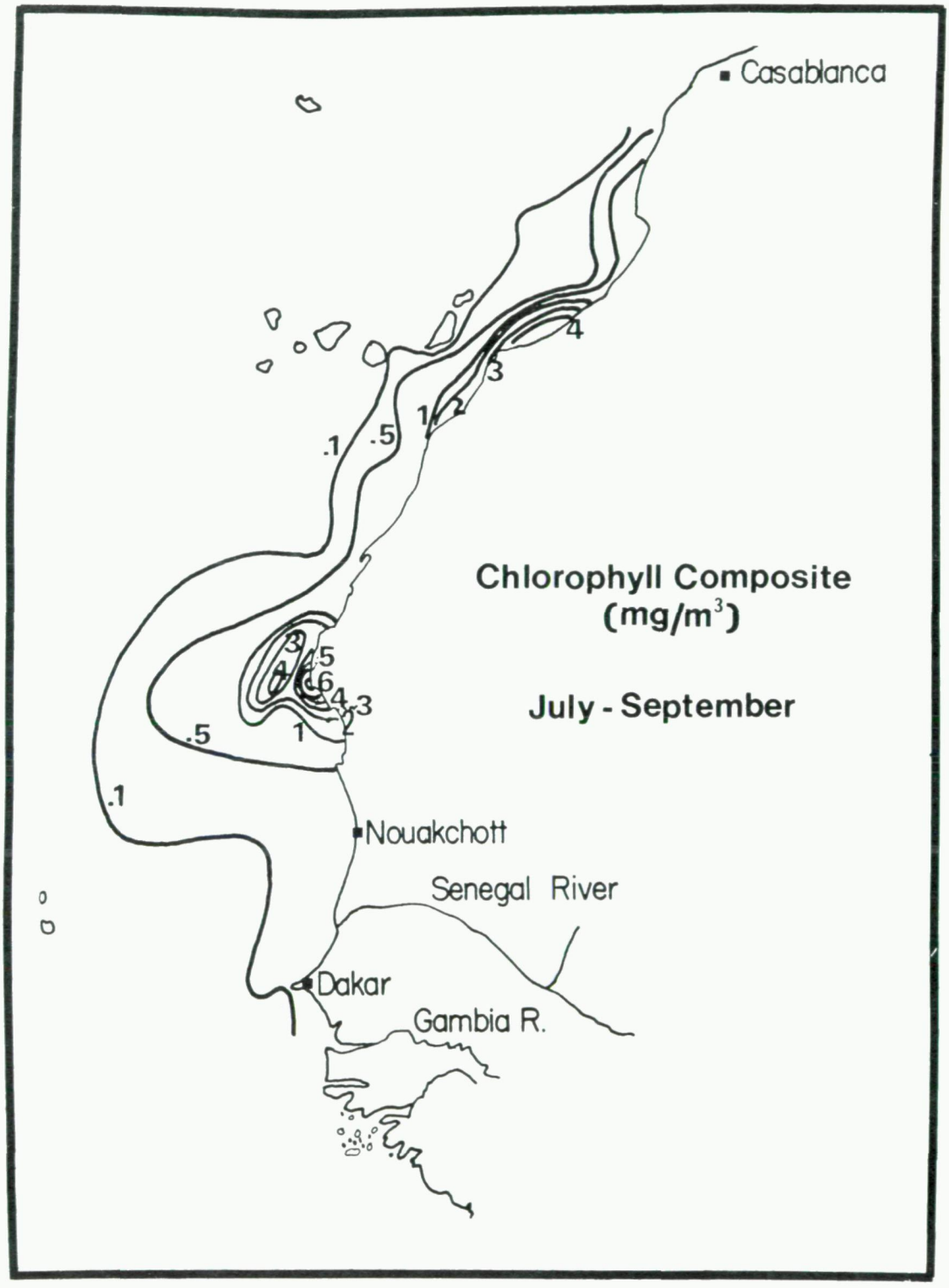


Figure 4. Composite of chlorophyll concentrations for the months July – September.

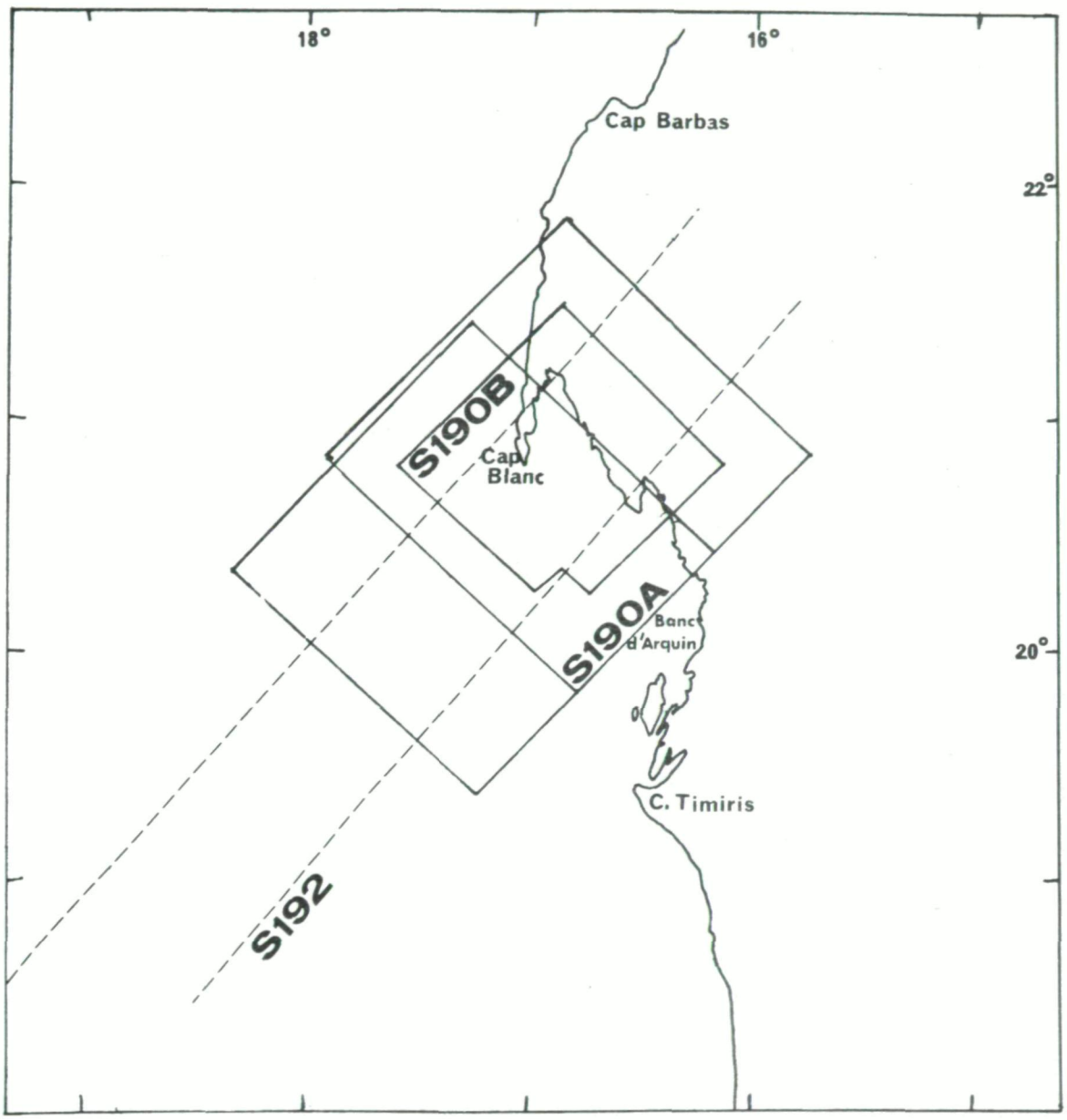


Figure 5. Ground coverage provided by the Skylab sensors during the 4 September 1973 overpass.

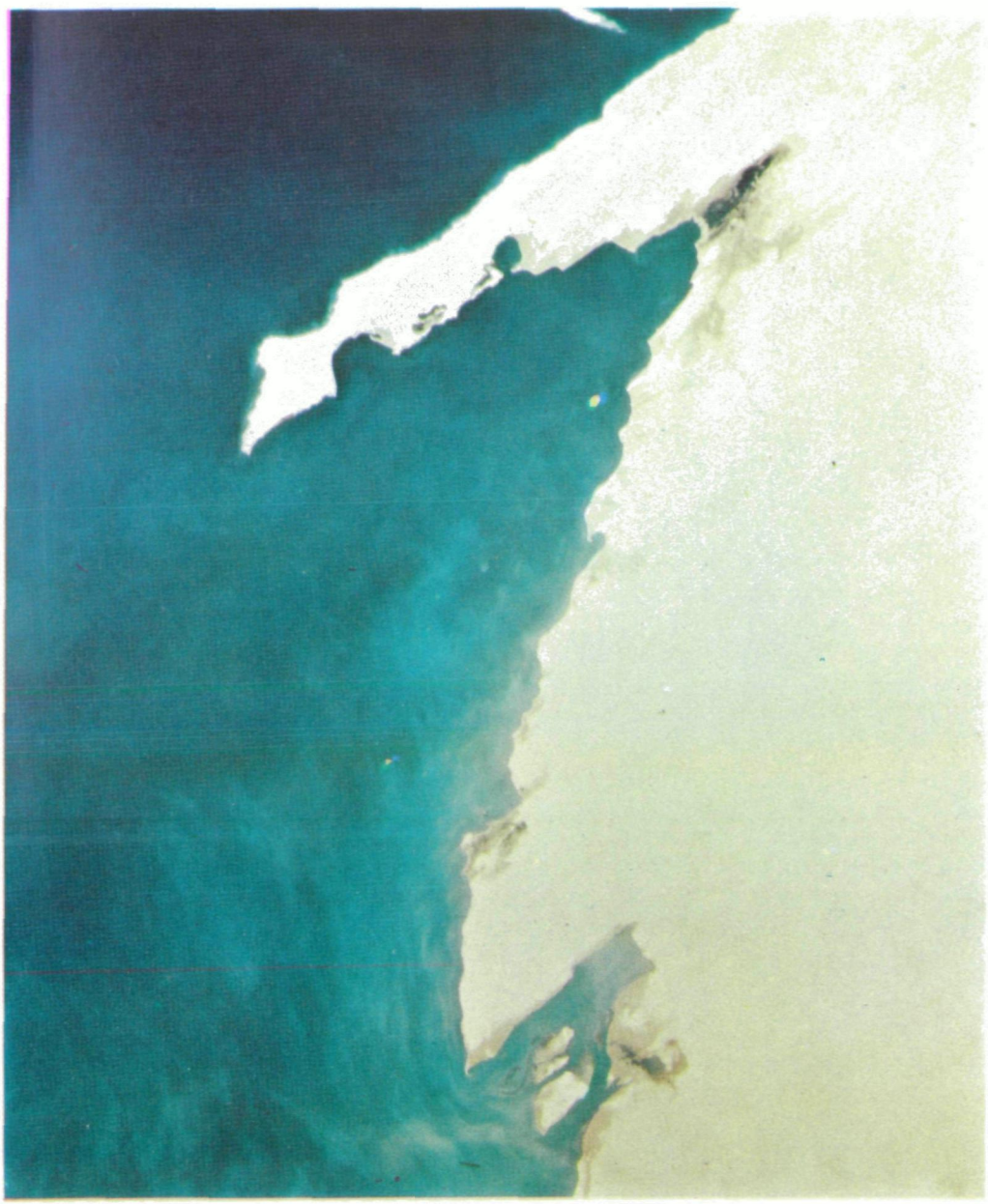


Figure 6. S190B color photograph of Cap[illegible]lanc.



Figure 7. Green band S190A image of Cape Blanc.

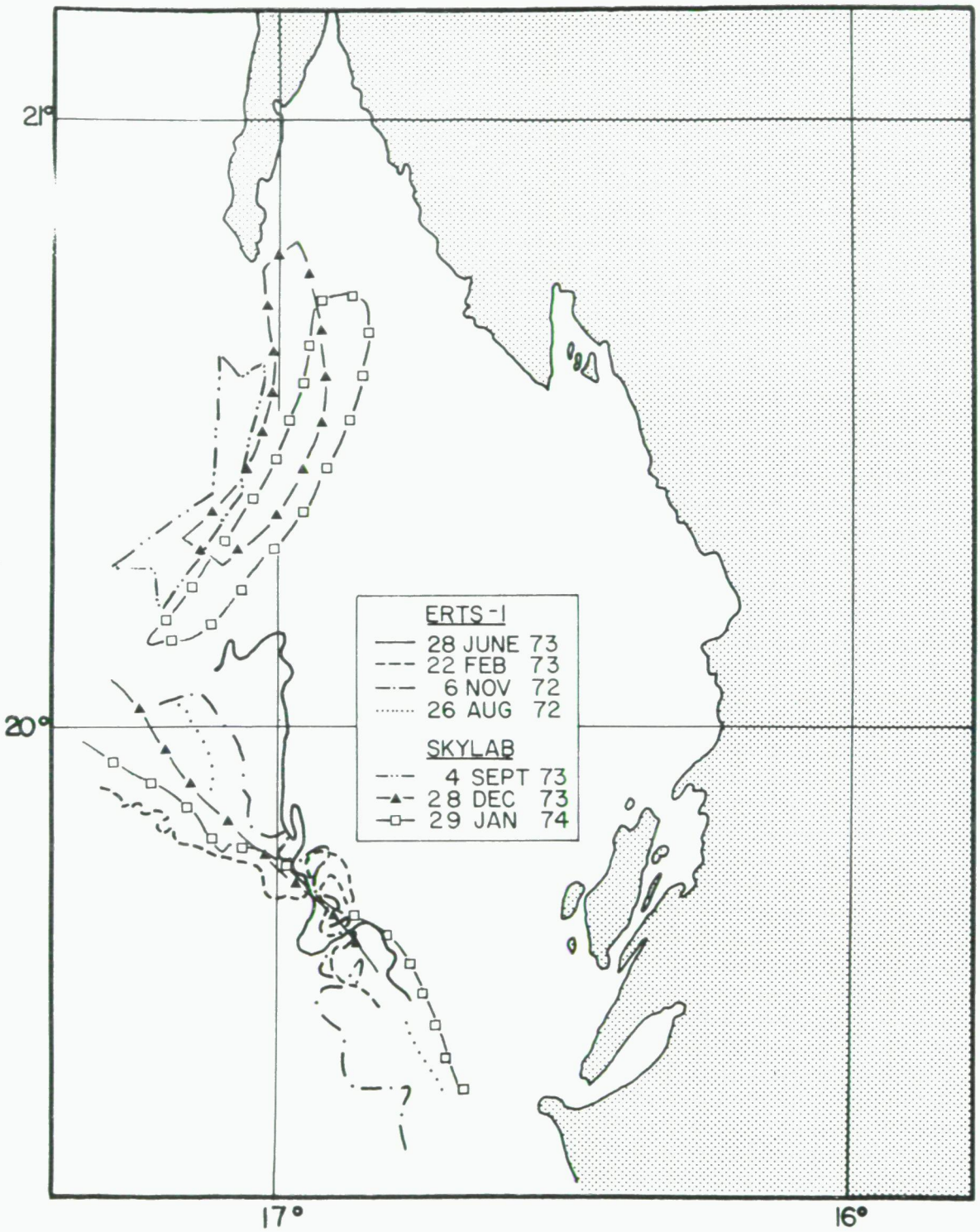


Figure 8. Offshore ocean color boundaries derived from LANDSAT-1 and Skylab.

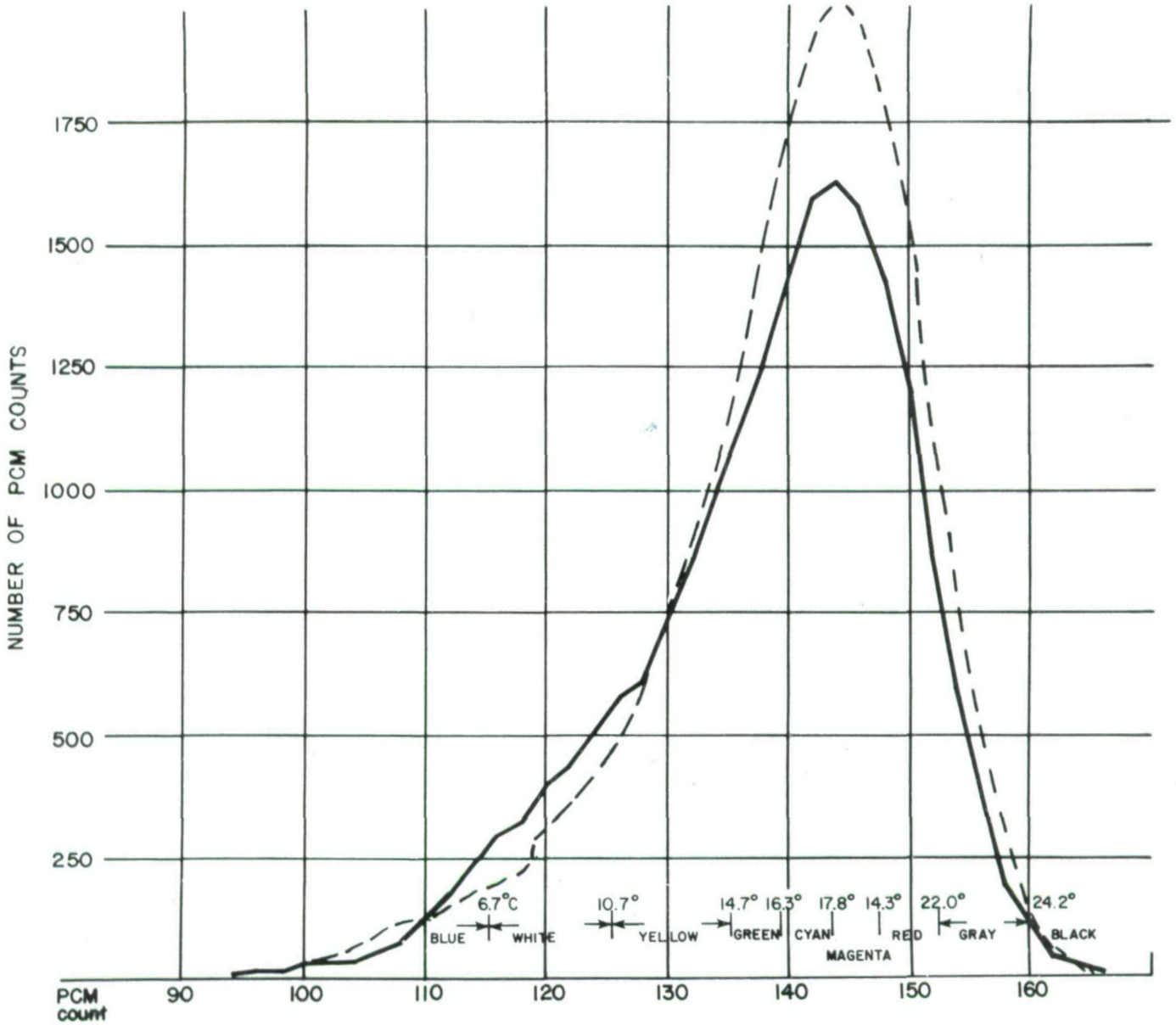


Figure 9. Histogram of thermal data and color coding for S192 imagery.

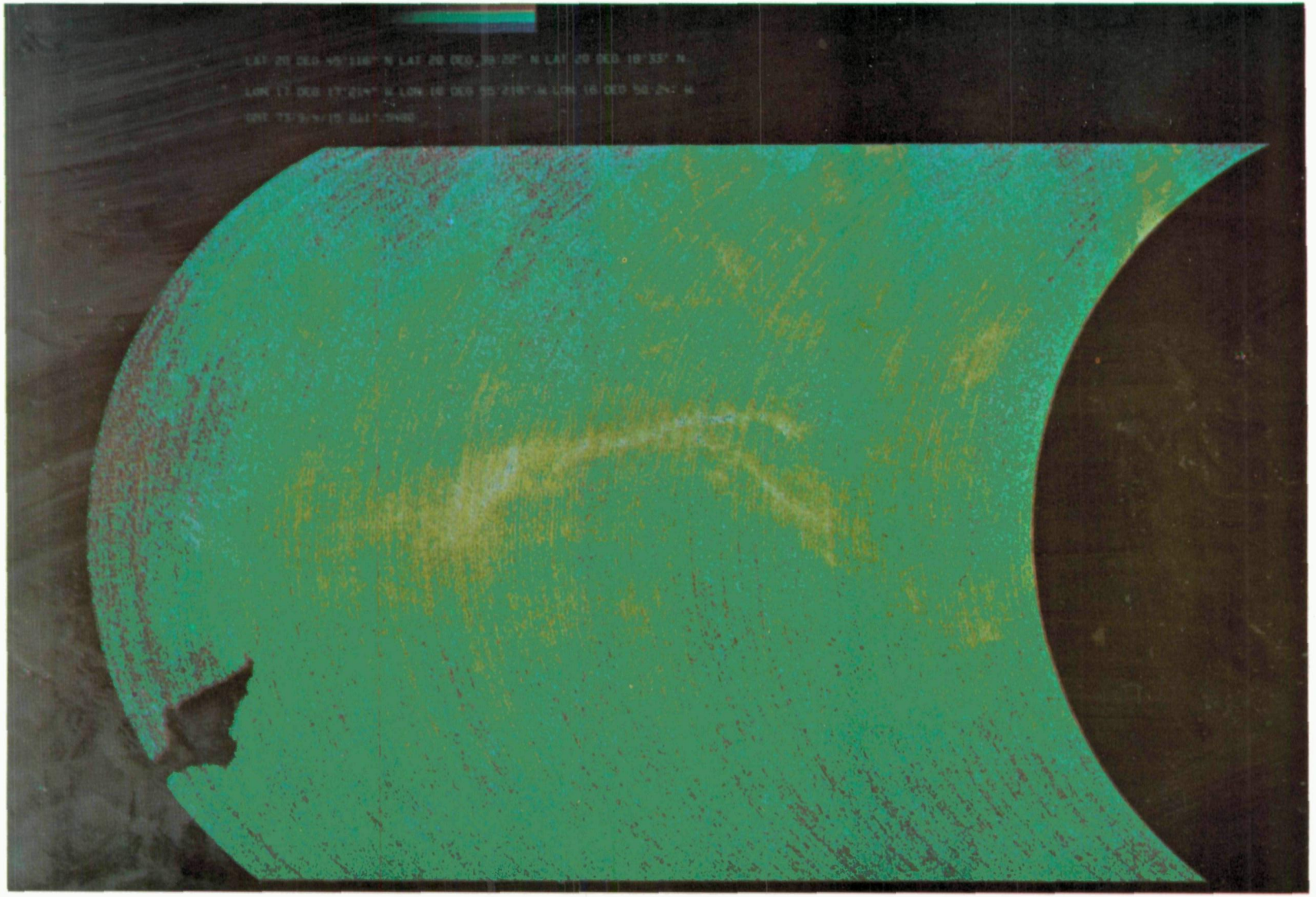


Figure 10. Color-coded temperature distribution derived from channel 13 of the S192 multispectral scanner.

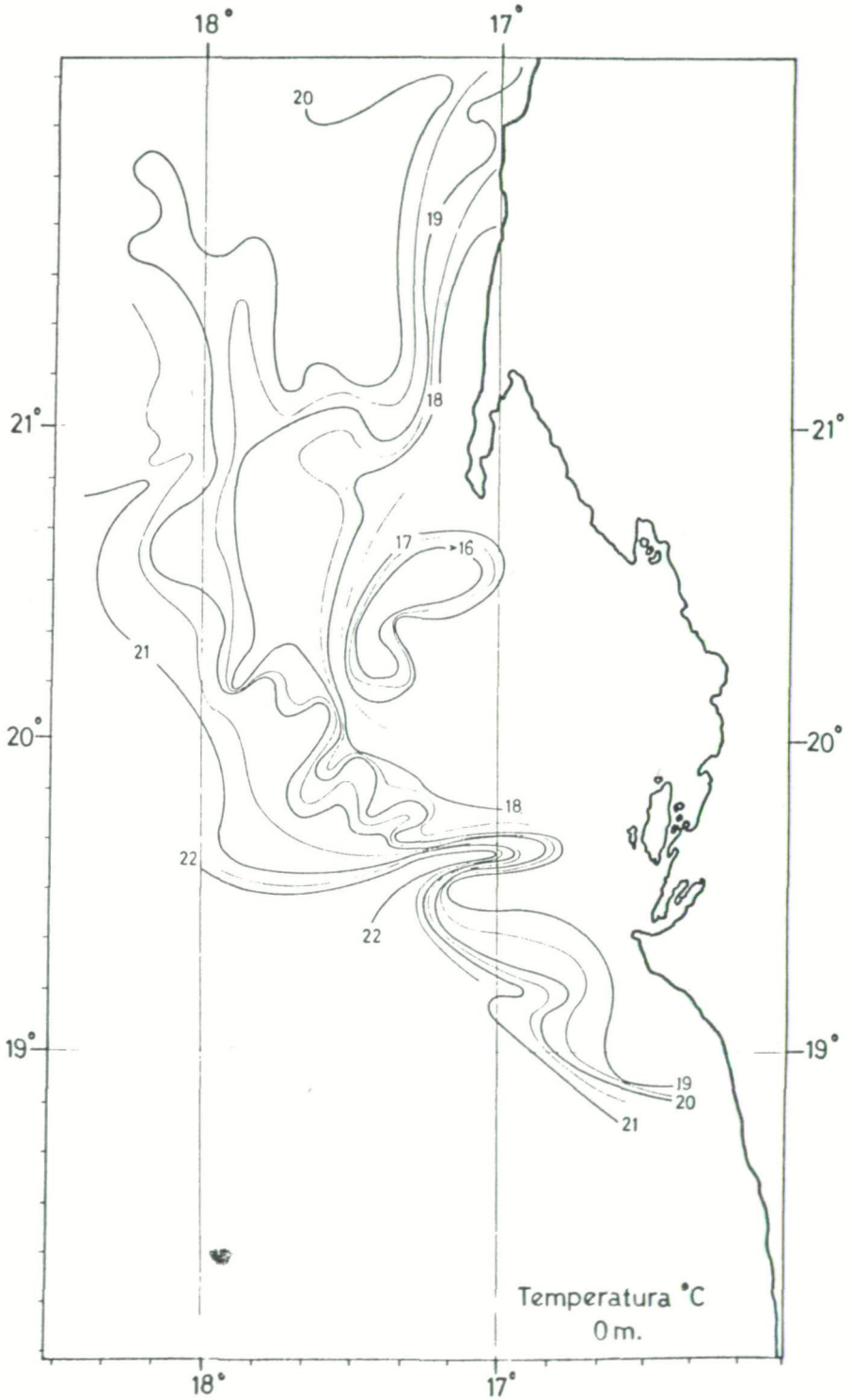


Figure 11. Temperature distribution between Cape Blanc and Cape Timiris observed in September 1972. (from Szekielda (1974)).

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THE FEASIBILITY OF UTILIZING REMOTELY SENSED DATA TO ASSESS AND MONITOR OCEANIC GAMEFISH

M-8

by

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ABSTRACT

An investigation was conducted to establish the feasibility of utilizing remotely sensed data acquired from aircraft and satellite platforms to provide information concerning the distribution and abundance of oceanic gamefish. The investigation is currently in its analysis phase. The data from the test area was jointly acquired by NASA, the Navy, the Air Force and NOAA/NMFS elements and private and professional fishermen in the northeastern Gulf of Mexico. The data collected has made it possible to identify fisheries significant environmental parameters for white marlin. Prediction models, based on catch data and surface truth information, have been developed and have demonstrated a potential for significantly reducing search by identifying areas that have a high probability of productivity. Three of the parameters utilized by the models, chlorophyll-a, sea surface temperature and turbidity were inferred from aircraft sensor data and have been tested. Effective use of Skylab data was inhibited by cloud cover and delayed delivery. Initial efforts toward establishing the feasibility of utilizing remotely sensed data to assess and monitor the distribution of oceanic gamefish has successfully identified fisheries significant oceanographic parameters and demonstrated the capability of remotely measuring most of the parameters.

INTRODUCTION

An oceanic gamefish investigation was initiated in April 1973 with the primary objective of determining the feasibility of utilizing remotely sensed data acquired from aircraft and satellite platforms to assess and monitor the distribution of oceanic gamefish. The project was contracted to the National Marine Fisheries Services (NMFS) Fisheries Engineering Laboratory (FEL) by the National Aeronautics and Space Administration (NASA) Lyndon B. Johnson Space Center (JSC). Many elements of the National Oceanic and Atmospheric Administration (NOAA), the Air Force, the Navy, NASA, as well as numerous professional and sports fishermen participated in the investigation. This joint effort was undertaken to acquire fishery and oceanographic data in association with near simultaneously acquired Skylab - 3 and aircraft remotely sensed environmental data. This paper presents a summary of the results of the investigation. Earlier papers (1)(2) described the field operations and preliminary results of the August 4 and 5 investigation. Another report (3) describes the remote sensing of Oceanic Parameters during the Skylab Gamefish experiment. A complete report of the investigation and its analysis is scheduled to be completed in June 1975.

TARGET RESOURCE

The target resource of this investigation, oceanic gamefish, included billfishes, dolphin, wahoo,

and certain of the tunas. These gamefish constitute a major source of recreation for an increasing number of salt water anglers. In addition to the increasing domestic pressure, the resource is being exploited by the Japanese longline fishery and there are indications (4) that the fishing intensity has reached or exceeded the level beyond which a maximum annual yield cannot be sustained. This and other resource investigations will hopefully provide valuable information for the application of new management techniques to protect the resource.

TEST AREA

The test area (Figure 1) comprised 18000 square kilometers and was shaped roughly like a triangle, bounded by the coordinates 30° 16'N, 86° 51'W; 29° 18'N, 85° 47'W; and 29° 21'N, 87° 56'W on the north, east, and west respectively. The northern apex was 14 kilometers south of Santa Rosa Island and the southern serrated edge extended 155 km south of the apex. The sides extending from the northern apex approximated the 55 meters curve along the coast. The northern extremity of the De Soto Canyon lay within the southern portion of the area providing depths in excess of 1600 meters. In order to provide a grid for referencing gamefish catches, the fishing area was divided into 54 squares with 18.3 km (10 nautical miles) to a side. Skylab track 62 approximately bisected the area, extending southeast from Mobile Bay.

The test area is noted for an abundance of oceanic gamefish during the summer season. Numerous marinas are located along the coast line. Several gamefishing clubs are headquartered in nearby coastal cities and charter boat gamefishing is a viable industry in the coast economy. Figure 2 depicts an operational overview of the test area.

FIELD OPERATIONS AND DATA ACQUISITION

Skylab EREP Imagery

The Skylab Earth Resources Experiment Package (EREP) overpass occurred at approximately 1140 CDT on August 5 with 40 to 70 percent scattered cumulus cloud cover below 3000 meters. Duration of the overpass was about 40 seconds as the satellite transited southeasterly over the test side from the direction of Mobile Bay. The sensors activated during the overpass are shown with their respective applications for the project in Table I.

Aircraft Imagery

Aircraft data gathering missions were flown in the area on the morning of 5 August. A NASA earth survey aircraft, the NC130B, based in Houston, Texas, flew three flight lines totaling 413 km through the area at 6100 meters altitude. A contract light aircraft flew transects totaling 413 km at 3000 meters altitude. The aircraft sensor coverage is given in Table II.

Gamefish Data

A committee of representatives from six gamefishing clubs and charterboat associations headquartered in Alabama, Florida, and Louisiana, coordinated the volunteer fishing program to acquire data on the living marine resource. These data were acquired through a Skylab Gamefish Tournament held August 4-5 under the general management of the Pensacola Big Game Fishing Club.

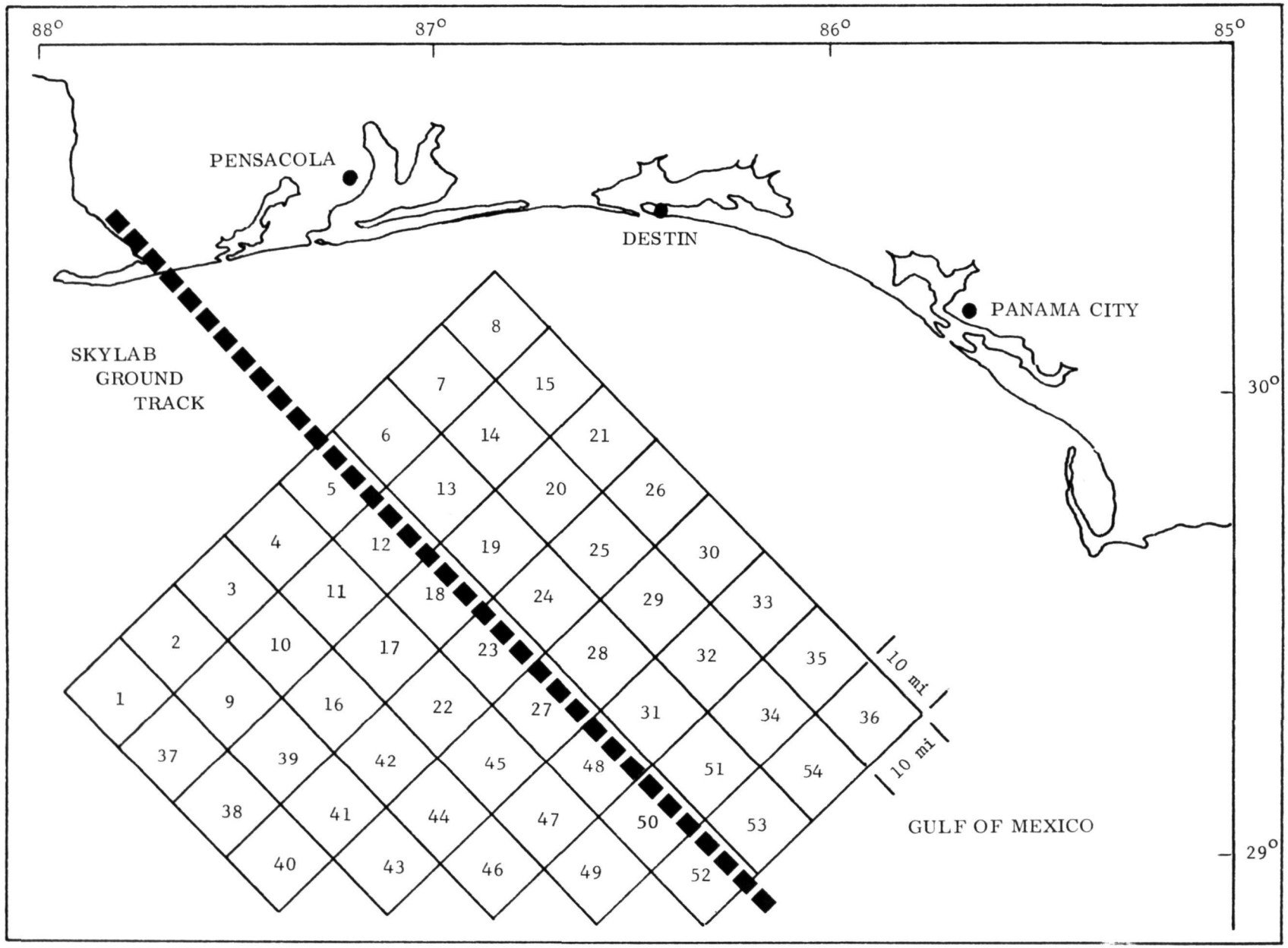


Figure 1. Test Area With Fishing Squares

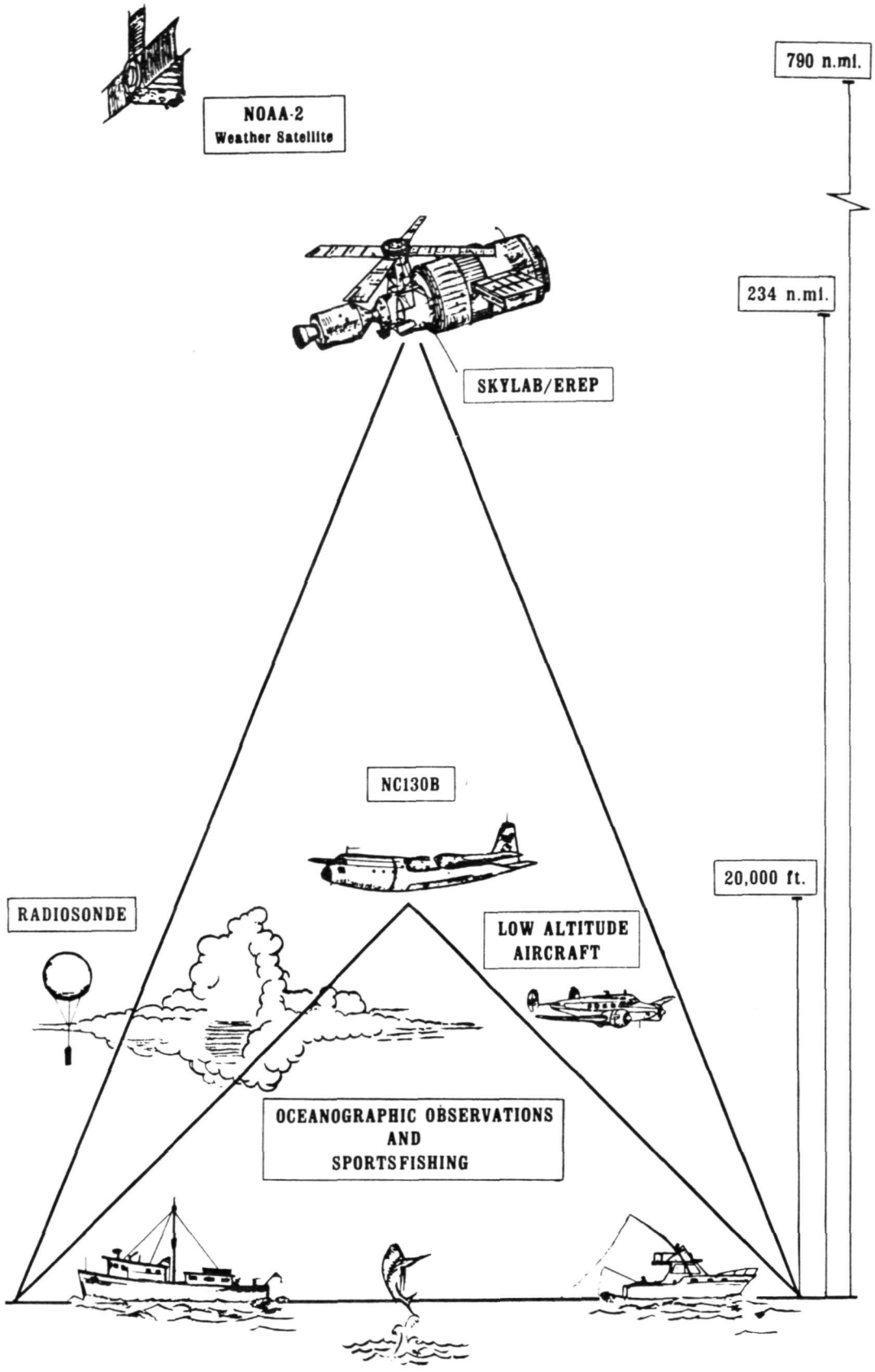


Figure 2. Operational Overview

TABLE I. SKYLAB EREP SENSORS ACTIVATED

INSTRUMENT	DESCRIPTION	FOOTPRINT	APPLICATION
S190 A	6 Cameras	163 km. wide	Water Color, Surface Features
S190 B	1 Camera	109 km. wide	Water Color, Surface Features
S191	Infrared Spectrometer	.43 km. wide	Water Color, Sea Surface Temperature
S192	Multispectral Scanner	74 km. wide	Water Color, Sea Surface Temperature
S194	Microwave Radiometer	109 km. wide (half power)	Sea Surface Salinity

TABLE II. AIRCRAFT SENSOR COVERAGE

INSTRUMENT	DESCRIPTION	FOOTPRINT	USE
NASA NC130B			
MSS	Multispectral Scanner	10.2 km	Sea Surface Temperature, Water Color
RECON IV	Infrared Scanner	7.0 km	Sea Surface Temperature
AMPS	Airborne Multispectral Photographic System	2.3 km	Water Color
RC8	Aerial Camera/Color Photography	9.1 km	Cloud Cover, Water Color, Location of Surface Vessels and Features
I^2S	Multiband Camera	5.3 km	Water Color
PRT 5	Precision Radiation	0.2 km	Water Color
NASA Light Aircraft			
RS-18	Thermal Infrared Scanner	7.3 km	Sea Surface Temperature
K-17	Aerial Camera/Color Photography	4.8 km	Water Color, Surface Features
EL 500	2 Cameras - Color and Color IR	4.2 km	Water Color, Surface Features
PRT 5	Precision Radiation Thermometer	0.1 km	Sea Surface Temperature
E 20-D	Spectrometer	0.1 km	Water Color

Fishing tournament officials restricted competition for trophies to seven offshore gamefish species.

Blue Marlin, Makaira nigricans
White Marlin, Tetrapturus albidus
Sailfish, Istiophorus platypterus
Wahoo, Acanthocybium solanderi
Dolphin, Coryphaena hippurus
Yellowfin Tuna, Thunnus albacares
Bluefin Tuna, Thunnus thynnus

Approximately 325 anglers fished from craft, 20 to 57 feet in length, scattered over the test area. On each boat a gamefish log was kept of all fish raised, hooked, lost and boated. Gamefish samplers collected the logs in the late afternoon at the checkpoints from the returning boats. At the time of submission, each log was reviewed by a gamefish sampler with the respective boat captain for omissions and errors while details still remained fresh in mind. Table III gives a breakdown of the fish catch.

Sea Truth Measurements

Data task teams on four Government and five Government-chartered vessels operating out of Orange Beach, Alabama; Destin, Florida; and Panama City, Florida, gathered sea truth environmental data at 48 sampling stations at periodic intervals during daylight hours on August 4 and 5. A total of 140 sets of measurements were taken.

TABLE III. TOURNAMENT FISH CATCH

Fish Species	No. Raised But Not Hooked		No. Hooked		No. Lost		No. Boated	
	4 Aug.	5 Aug.	4 Aug.	5 Aug.	4 Aug.	5 Aug.	4 Aug.	5 Aug.
	BILLFISH							
Blue Marlin	5	3	6	5	6	5	0	0
White Marlin	25	19	32	23	9	14	23	9
Sailfish	4	5	10	4	6	3	4	1
Total Each Day	34	27	48	32	21	22	27	10
	OTHER GAMEFISH							
Yellowfin Tuna	0	0	0	0	0	0	0	0
Bluefin Tuna	0	0	0	0	0	0	0	0
Dolphin	2	0	32	43	5	5	27	38
Wahoo	4	0	10	6	2	3	8	3
Total Each Day	6	0	42	49	7	8	35	41
	ALL TOURNAMENT GAMEFISH							
Total Each Day	40	27	90	81	28	30	62	51
Tournament Totals	67		171		58		113	

Parameters measured for each set included surface water temperature, air temperature, Secchi disc extinction depth (as a measure of turbidity), sea state, wind direction and speed, wet and dry bulb temperature, water depth, atmospheric pressure, visibility, cloud cover and type, and water color. Sea water samples were also taken for laboratory analysis for salinity and chlorophyll-a, -b, and -c. The Forel-Ule color comparator was used to determine water color. Sea surface temperature was obtained by means of a bucket thermometer. In addition, portable salinometers were used on several vessels to obtain in situ salinity and temperature measurements.

In addition to data acquisition by the oceanographic vessels, scientific observers on twelve of the larger gamefishing boats collected sea truth data coincident with gamefish catches. A total of 75 sets of measurements were taken by these observers. Parameters measured were the same as those measured from the oceanographic boats except that chlorophyll samples were not taken. Psychrometer readings were taken on only a few boats.

DATA ANALYSIS

Approach

The sensors used in this investigation did not have the capability for direct observation of gamefish and had only limited capability for acquisition of information related to surface or near-surface phenomena. Therefore, the main thrust of the data analysis utilized an indirect approach with intermediate correlations. The resource data and remotely sensed information were separately related to the sea environment as observed by surface sampling and related through the sea environment to each other (Figure 3). An effort to relate surface phenomena directly with the incidence of gamefish was unavailing.

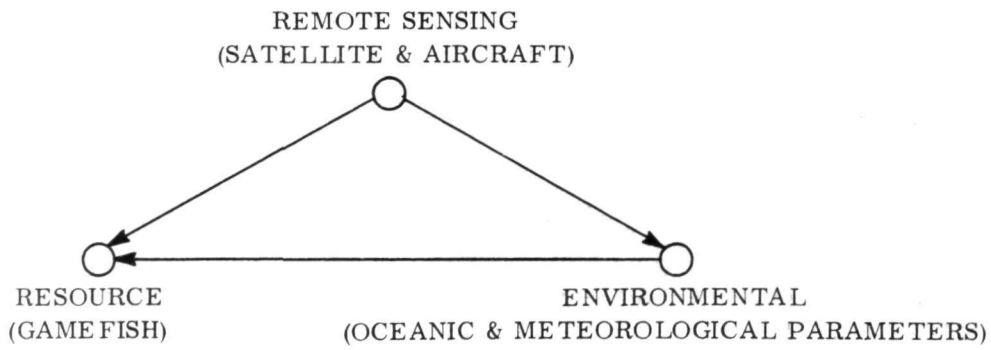


Figure 3. Analysis Approach

The objective of the analysis was to produce a prediction model, using oceanographic values inferred from remotely sensed data, which could be used as a management tool for resource utilization.

RESOURCE AND SEA TRUTH RELATIONSHIPS

Concept

The concept employed in the analysis was that oceanic gamefish abundance and distribution can be expressed as a function of the environment, which is similar to that concept expressed in a

previous fisheries remote sensing paper (5). The functional dependence is described in the following algebraic expressions.

$$A_{x,y} = f(E)$$

$$D_{x,y} = g(E)$$

where:

A = number of oceanic gamefish
x,y = fish location coordinates
E = environmental conditions at x,y
D = gamefish distribution parameters

$$D = \begin{cases} 0 & \text{no fish present} \\ 1 & \text{fish present} \end{cases}$$

The abundance parameter, $A_{x,y}$, was estimated by oceanic gamefish raised only, hooked, lost, or boated by the fishermen and therefore has a larger degree of error due to the ability of anglers to identify, attract, hook and land the fish. The distribution parameter, $D_{x,y}$, by its definition was less susceptible to error than the abundance parameter, $A_{x,y}$, and therefore was utilized in the mathematical modeling efforts.

Data Preparation

Resource information was available for only 34 out of the 54 fishing squares on 4 August and 30 out of the 54 squares on 5 August. However, environmental information was not obtained from some squares for which there were catch data. Accordingly, an averaging technique was used to provide environmental information for those squares where resource data had been recorded. The technique consisted of averaging the values of all encircling squares and has previously been used for interpolating catch data (6). Furthermore, individual test square values for each parameter were computed by averaging all station readings in that square for that parameter each day. Environmental data for each square fished consisted of the following parameters: surface water temperature, surface salinity, air temperature, Secchi extinction depth, sea state, Forel-Ule water color, chlorophyll-a, chlorophyll-b, chlorophyll-c, water depth, and distance from shore. These parameters were utilized as independent variables in the initial correlation analyses. Atmospheric pressure was eliminated from the analyses because of the limited number of stations for which this measurement was reported.

It was decided to concentrate efforts on a billfish and a non-billfish species. White marlin and dolphin respectively were selected for study because a relatively large catch data set was available for each. The white marlin was selected initially because interest seemed to focus on billfish and accordingly, much of the text on the progress of the analyses relates to white marlin.

Initial correlation analyses were made to determine which form of the resource abundance and distribution parameters (fish raised only, hooked, raised plus hooked, or boated) should be used. The hooked parameter was found to have the strongest correlation with the environmental parameters. This stronger correlation can be explained by less error in this measurement as compared to the raised parameter, i.e., there is less chance of incorrect identification once the fish is hooked. Conversely, the boated parameter, which had no possibility of identification error, caused a significant error in the distribution parameter, $D_{x,y}$, when the fish was hooked and not boated.

Therefore, the hooked form of the parameter was used in correlation analyses and mathematical modeling.

Further error was identified in the resource distribution parameter in that a certain level of fishing pressure was required to determine if there were fish in a fishing square. In other words, if fishing pressure was insufficient in a given square, the distribution parameter would have a value of 0 regardless of the presence or absence of fish. This would tend to conceal relationships between the resource and the environment. Having found that no white marlin were caught in any of the test squares with less than 4 boat hours of fishing pressure, a correction for this error was made by eliminating from the analyses all squares having less than 4 boat hours of fishing pressure. This resulted in narrowing the study to 24 out of the 34 test squares remaining for 4 August, and 22 out of the 30 remaining for 5 August.

Correlation Analysis

Correlation and regression techniques were utilized to define relationships between the resource and the environment as defined by sea truth measurements. The number of white marlin hooked in each test square was utilized as a measure of abundance ($A_{x,y}$) and converted to form the distribution parameter ($D_{x,y}$). Linear correlation coefficients were computed for white marlin abundance and distribution and each of the environmental parameters (Table IV) measured on 4-5 August. The results listed in Table IV show a difference between abundance and distribution and probably reflect error in the abundance parameter. The dubious quality of the abundance parameter led to emphasis on the distribution parameter in the modeling efforts. It should be stressed here that the correlation coefficients are a measure of the linear relationships between the given dependent variables and each environmental parameter respectively, and do not necessarily indicate the set of parameters which should be used in developing predictive models. This is due to the fact that in some cases the parameters listed are also statistically correlated. For example, in the test area, water depth and distance from shore have a correlation coefficient of .832 which is significant at the 99% level. Hence, these two parameters are not statistically independent and one or possibly both (depending on interrelation with other parameters) may not be selected as a model parameter. However, the correlation coefficients listed in Table IV provide a measure of the linear relationship (within this set of data) between the white marlin parameters and each of the environmental parameters.

Assignment of biological significance to these correlations was not within the scope of this study. The parameters measured may only be serving as indices of unmeasured parameters. Other investigators (7) have also found temperature to be related to fish distribution. In analyses of the distribution of white marlin Gibbs (7) found that successful white marlin longline sets were made in surface water temperatures above 24°C. Since the fishing data were collected in August when the Gulf is nearly uniform in surface temperature, 29°C (8), the large catch of white marlin was not unexpected. A factor which should be noted here is that there was a correlation coefficient of .407 significant at the 99% level for white marlin distribution and temperature with all of the sampled temperatures measuring between 28.5°C and 31.6°C. The strong positive correlation held true for data taken on both days as well as the combined data sets.

There is no evidence of correlation of either distribution or abundance with depth of water according to Gibbs (7). Thus, the apparent strong depth correlation listed in Table IV may be valid only in this particular test area and may be seasonal or coincidental.

Positive correlations (significant at the 90% level) between white marlin distribution and the chlorophyll-a and c (phytoplankton measurements) were found. This may be compared to a white marlin study in the Middle Atlantic Bight where important marlin areas showed distinctly high zoo-

TABLE IV. CORRELATIONS BETWEEN WHITE MARLIN (HOOKED) ABUNDANCE ($A_{x,y}$) AND DISTRIBUTION ($D_{x,y}$) ESTIMATES AND SAMPLED ENVIRONMENTAL PARAMETERS (E)

Parameter	Degrees of Freedom	Correlation Coefficient (r)	
		Distribution	Abundance
Water Temperature (°C)	44	.407***	.310**
Salinity (ppt)	44	-.145	.001
Air Temperature (°C)	44	.113	.218*
Secchi Transparency (m)	44	.129	.269**
Sea State (m)	44	.272**	.183
Forel-Ule Color (units)	44	-.180	-.044
Chlorophyll-a (mg/m^3)	44	.200*	.054
Chlorophyll-b (mg/m^3)	44	.056	-.005
Chlorophyll-c (mg/m^3)	44	.214*	.241*
Water Depth (m)	44	.329**	.170
Distance from Shore (km)	44	.454***	.323**

* 90% significance level ** 95% significance level *** 99% significance level

plankton volumes (9). The comparison tends to support the correlation if one assumes that zooplankton abundance is a function of phytoplankton abundance.

As planned, subsequent to the white marlin analysis, correlations were investigated for 4 and 5 August and the combined dates between dolphin distribution and abundance and the environmental parameters - sea surface temperature, salinity, air temperature, Secchi extinction depth, sea state, Forel-Ule color, water density and chlorophyll-a, -b, and c. Instability was found to exist for all relationships on a day to day comparison. The extent of the instability discouraged development and testing of prediction distribution and abundance models for dolphin such as were accomplished for white marlin.

REMOTELY SENSED OCEANOGRAPHIC PARAMETERS AND CORRELATIONS WITH THE ENVIRONMENT

The object of this phase of the experiment was to measure water surface temperature, turbidity, and chlorophyll concentration from aircraft and satellite. Techniques currently under development

by the NASA ERL were used for the measurements.

Sea Surface Temperature

The remote measurement of sea surface temperature has been widely studied. Absolute accuracies of 0.5°C are readily obtainable from aircraft measurements using one, or in some cases no ground truth calibration (10) (11) (12) (13).

The aircraft thermal data were taken from 3000 meters with an RS-18 scanning radiometer and a PRT-5 radiometer and also from 6100 meters with another PRT-5 radiometer. These radiometers are sensitive in the 8-14 μm regions of the spectrum. The aircraft thermal data have been processed and a radiometric temperature trace along the flight lines developed (Figure 4). From this trace, the temperature at points between the flight lines was interpolated to provide the basis of the contour map shown in Figure 5. For comparison purposes, the contour map of surface temperature determined by surface measurements and corrected for insolation during the ten-hour period of sampling to a time midway through the remote data acquisition exercise is presented in Figure 6. The time correction was performed by computing the change in temperature averaged over the test area on an hourly basis and adding the appropriate change to readings made at times different from the normalization time. A composite of the thermal data from the two aircraft was made to fill in gaps that occurred at different locations along the flight lines for the two aircraft caused by time-varying cloud cover. There were, however, several locations along the flight lines where clouds caused a total loss of data, and other locations where anomalous temperature measurements may have resulted from severe variations of atmospheric conditions.

Comparison of the surface and remote temperature contour maps shows that, while they are not identical, the same basic trends are present in both maps. There are two likely explanations for the discrepancies. The surface measurements were made by many individuals under different conditions, which could easily result in measurement errors of up to 0.2°C (14). Because of the 0.25°C contour interval, errors of this magnitude would distort the contour patterns. A second explanation is the heterogeneous atmosphere perturbing the remotely measured surface temperature. Analysis of general atmospheric conditions over the test area shows that a variation of 0.23°C can be expected excluding local anomalies due to cloud formations.

It was anticipated that Skylab S192 data would provide thermal measurements over the entire test area. However, analysis of the S192 thermal data has been delayed until June 1975.

Chlorophyll

Measurement of chlorophyll-a concentration obtained from radiance measurements has been attempted with varying degrees of success by many workers (15) (16) (17). No technique has apparently achieved either sufficient accuracy or consistency to be generally accepted as the best remote measurement method. The remote data processed in the study thus far were obtained by an Exotech 20-D spectral radiometer, flown on the light aircraft at 3000 meters. The instrument, as configured for this experiment, measured radiance in the region of the spectrum from 390 to 1100 nanometers (nm) and calibrated at 57 wavelengths in that range.

An algorithm for computing chlorophyll-a concentration developed by Weldon (15) has been used successfully with data taken with this radiometer, but at lower altitudes over the Mississippi Sound. Weldon's technique consists of a linear function of the difference between the radiance at 620 and 470 nm, normalized by the radiance at 520 nm. The coefficients of the function are determined

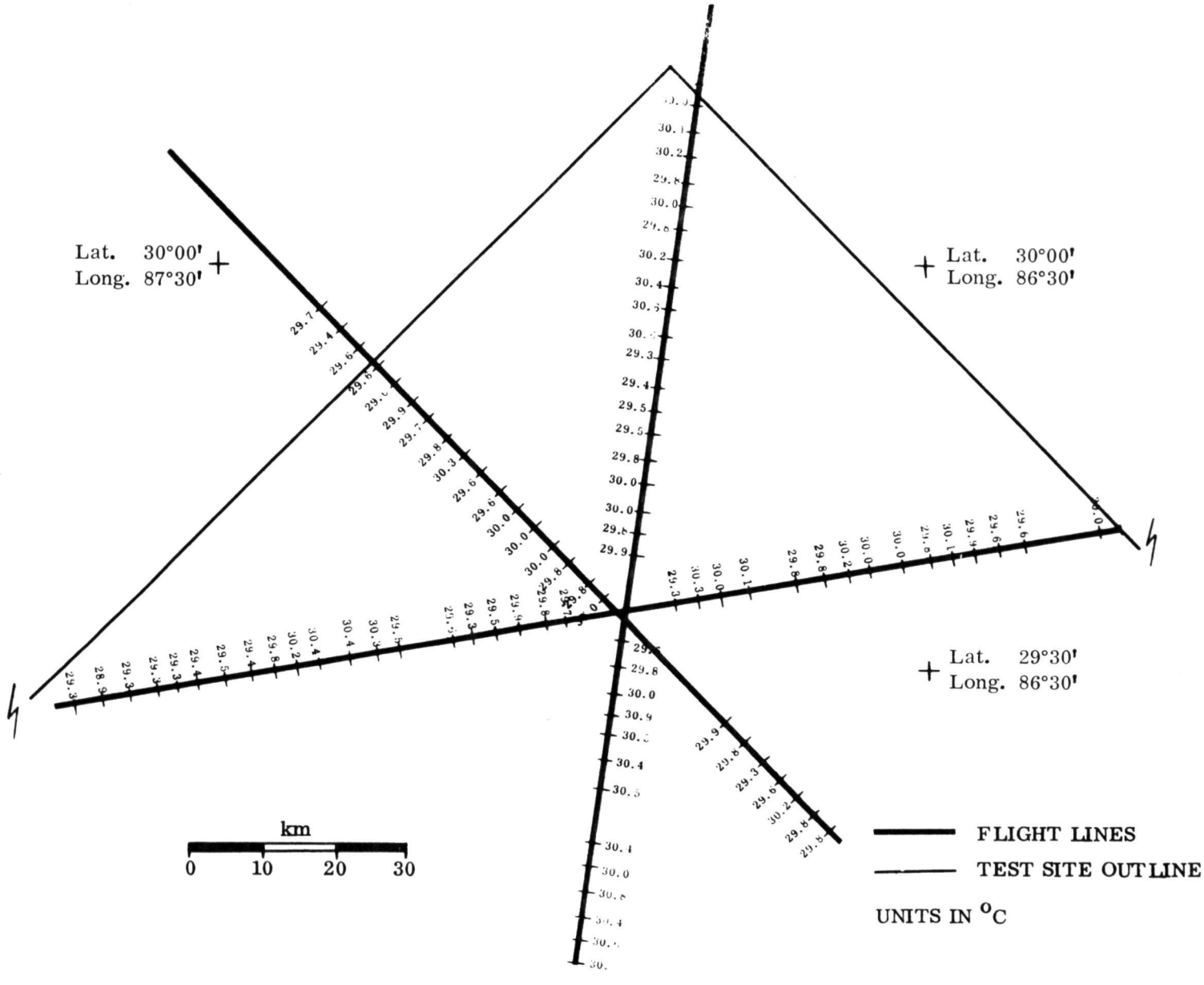


Figure 4. Radiometer Temperature Trace Along Flight Lines

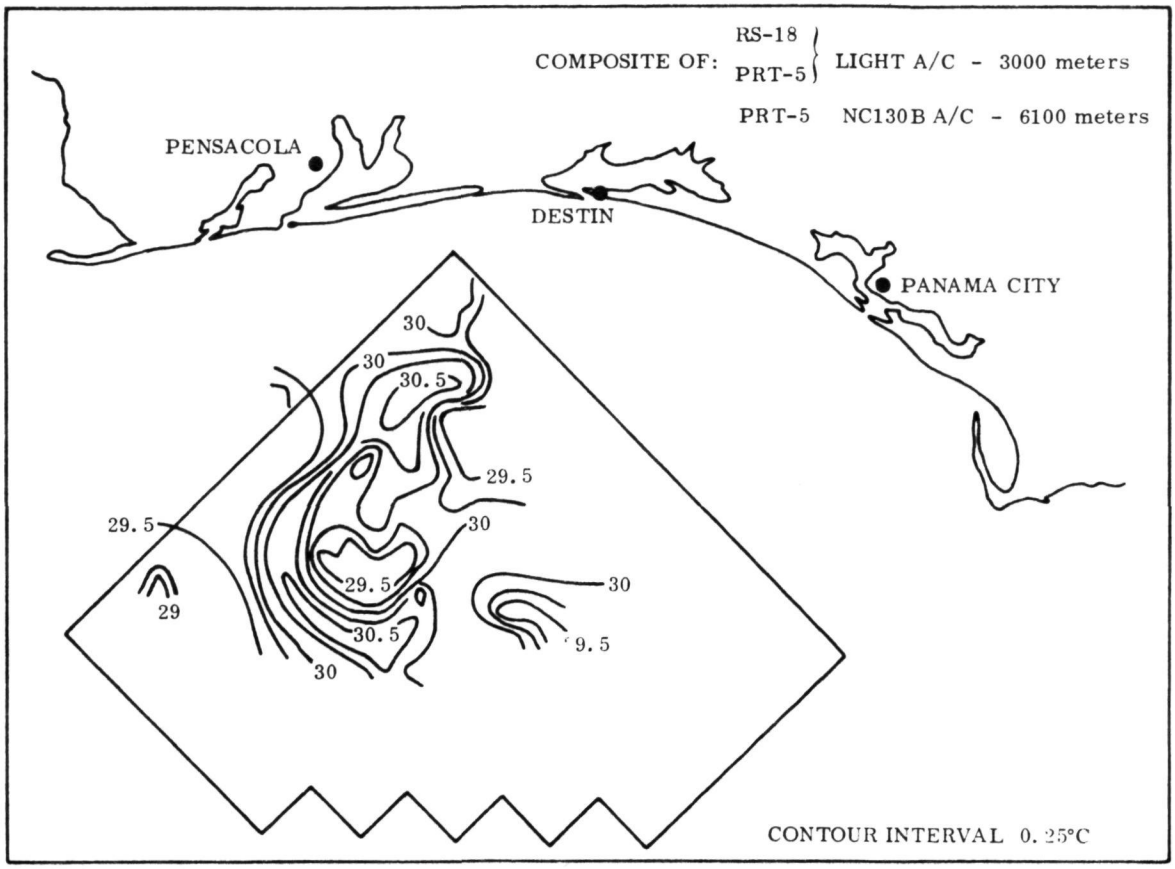


Figure 5. Remote Measurement of Water Temperature

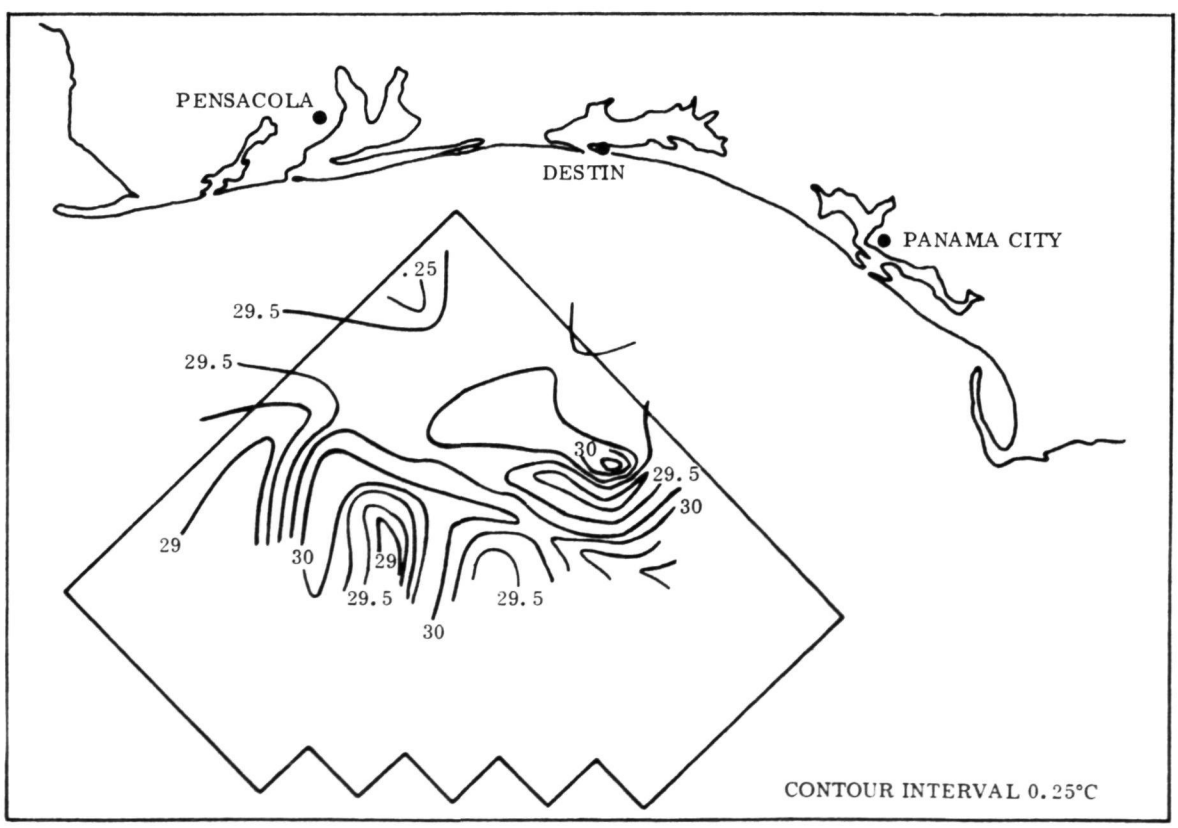


Figure 6. Surface Measurement of Water Temperature

from ground truth data.

$$C_W = \alpha_1 (R_{620} - R_{470}) / R_{520} + \alpha_2 \qquad (a)$$

This algorithm was applied to the data acquired in this experiment. The root mean square (rms) deviation of these calculations from the surface measurements was 0.48 mg/m^3 for 18 measurement points, of which nine were used for calibration.

Another technique was used for computing chlorophyll-a concentrations. Examination of the correlation of the 520 nm normalized radiance at each of the 57 wavelengths indicated that the chlorophyll-a concentration was highly correlated with the radiance at 470 and 600 nm. Further analysis showed that a linear combination of these radiance values correlated very well with the square of the chlorophyll-a concentration, so a second calculation of the chlorophyll-a concentration based on spectral radiometer measurements was made using the relation shown in Equation (b).

$$C_c = \sqrt{\alpha_1 (R_{600} - R_{470})/R_{520} + \alpha_2} \qquad (b)$$

Figures 7 and 8 are the contour maps drawn from the surface and remote measurements of chlorophyll-a, respectively. The remote measurements are a composite (Figure 9) of the results of both calculations. Careful examination of the two sets of measurements showed that the second gave better results in areas where chlorophyll-a content was low (0.28 mg/m^3 rms error), but that the response flattened out at concentrations above 2.3 mg/m^3. The first technique was better at the higher concentrations, so when a concentration greater than 2.0 mg/m^3 was indicated by the second technique, the value predicted by the first technique was used; otherwise, the value was that computed from Equation (b). The rms deviation of the composite at the 18 surface comparison points was 0.44 mg/m^3.

Comparison of Figures 7 and 8 shows that, while the maps do show significant differences, the large variations present in the surface data are also found in the remote data. This may be readily observed in Figure 10 which is a comparison of chlorophyll-a remote and surface measurement profiles along flight line two. In addition, there are some rapid changes indicated in the remote data which are not seen in the surface data. This does not mean that either measurement is in error; the remote data is a continuous sampling while the surface measurements are separated by approximately an hour's cruise. Another factor to be considered is the 10% repeatability factor (18) of the surface chlorophyll-a determination. It must also be remembered that no corrections for atmospheric conditions were made. These conditions were not constant over the test area, and clouds and cloud shadows do affect the apparent color and hence the inferred chlorophyll-a content.

Turbidity

For this experiment, turbidity was measured as Secchi extinction depth. This surface truth measurement of turbidity was used because of operational considerations, i.e., the technique is simple and the necessary equipment inexpensive. However, the measurement is subjective because of the human factor involved and is thus susceptible to considerable error.

Weldon (15) developed an algorithm for computing Secchi extinction depth from spectral radiometer measurements, so the first attempted remote measurement of turbidity was with this technique. Weldon (15) found that the Secchi extinction depth was proportional to the ratio of the radiance measured at 600 nm to that at 550 nm, but application of this algorithm to the data acquired in

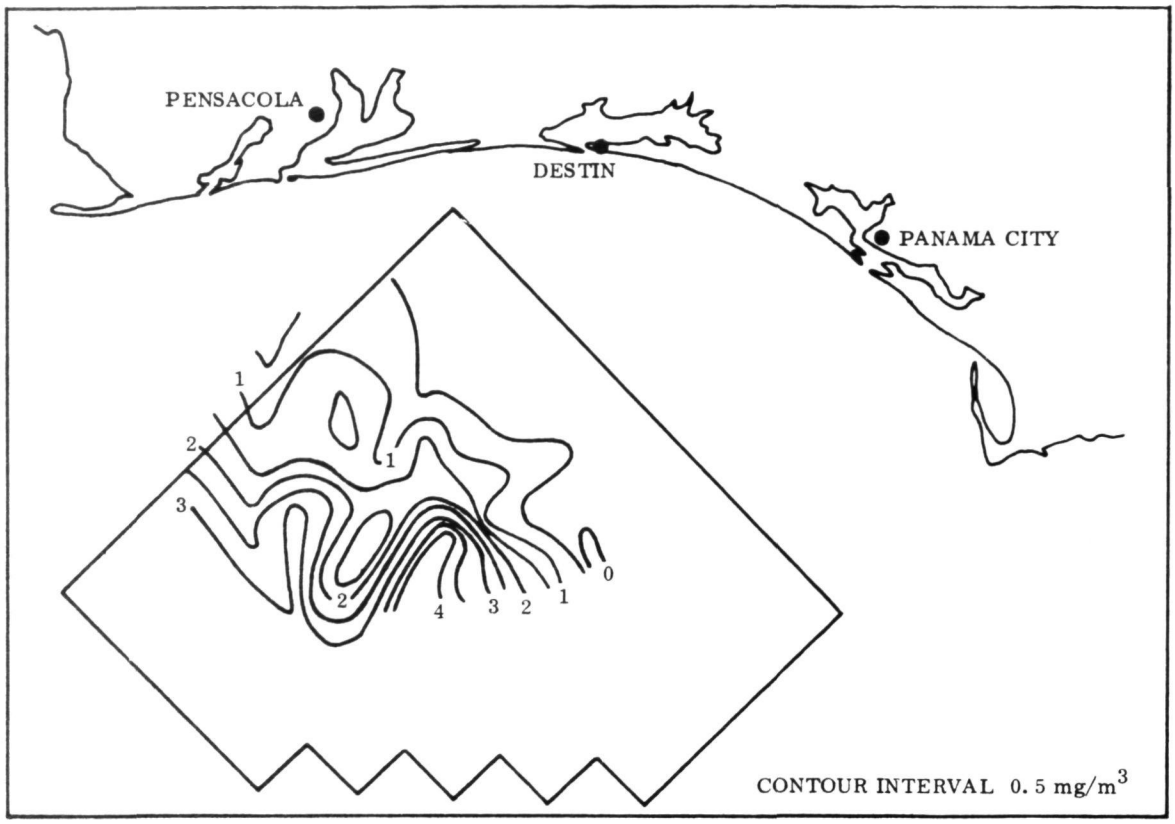


Figure 7. Surface Measurement of Chlorophyll-a

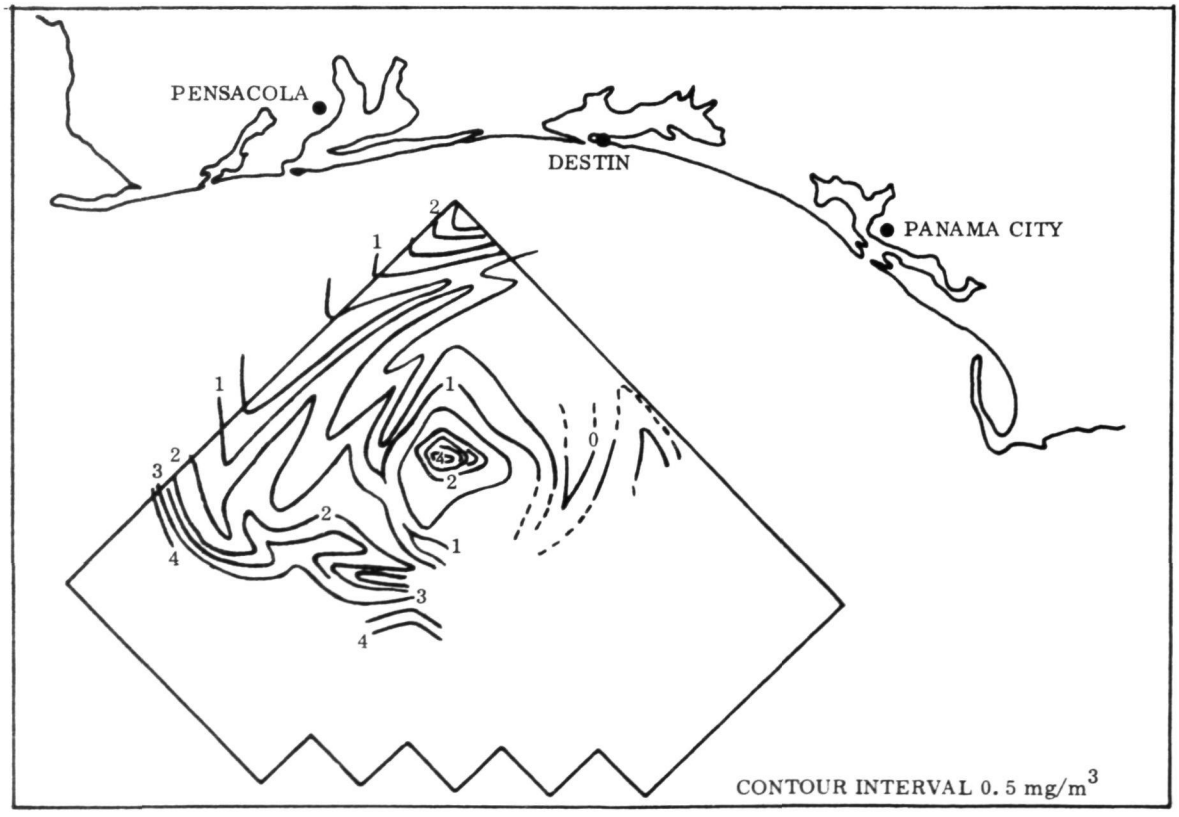


Figure 8. Remote Measurement of Chlorophyll-a

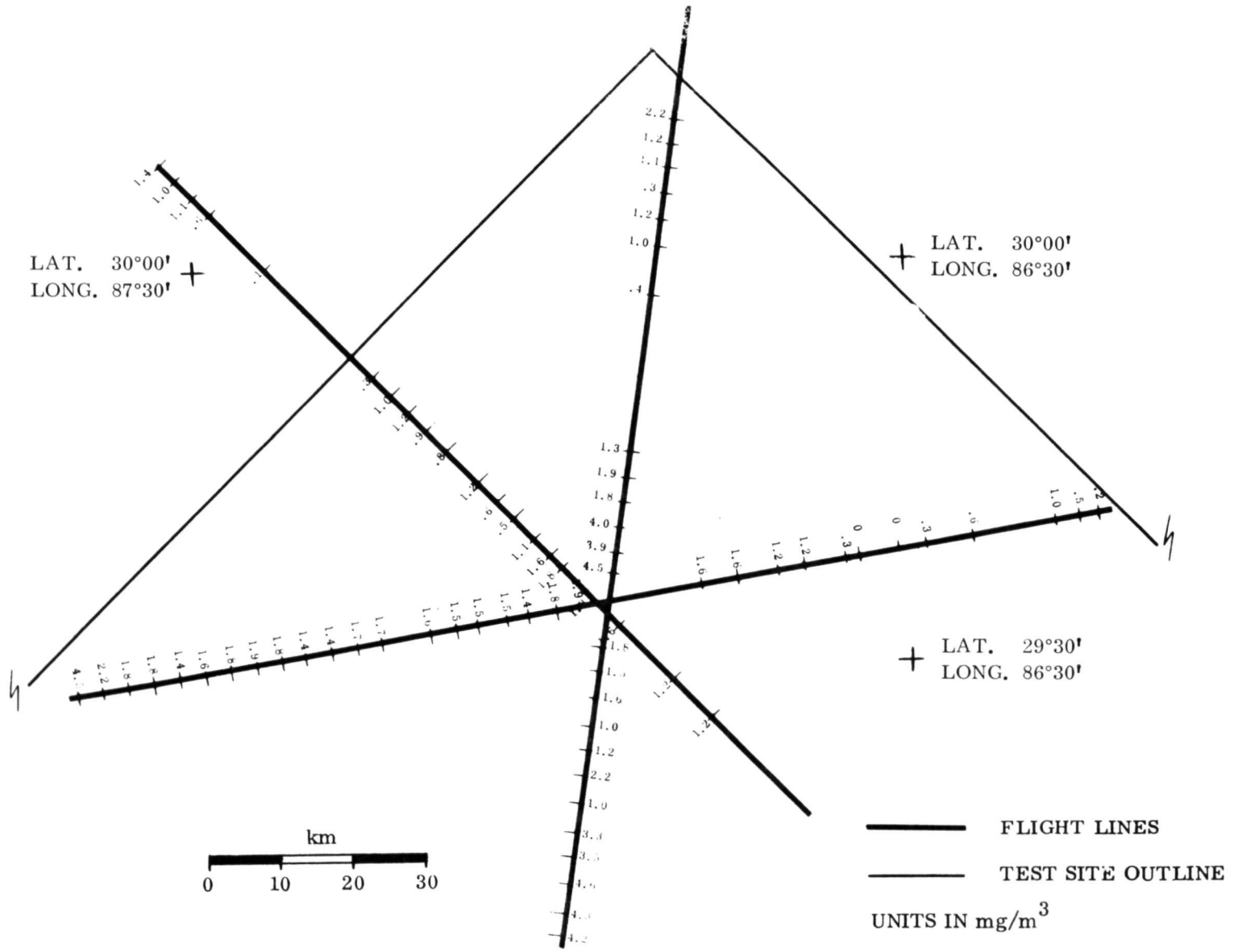


Figure 9. Chlorophyll-a Along Flight Lines

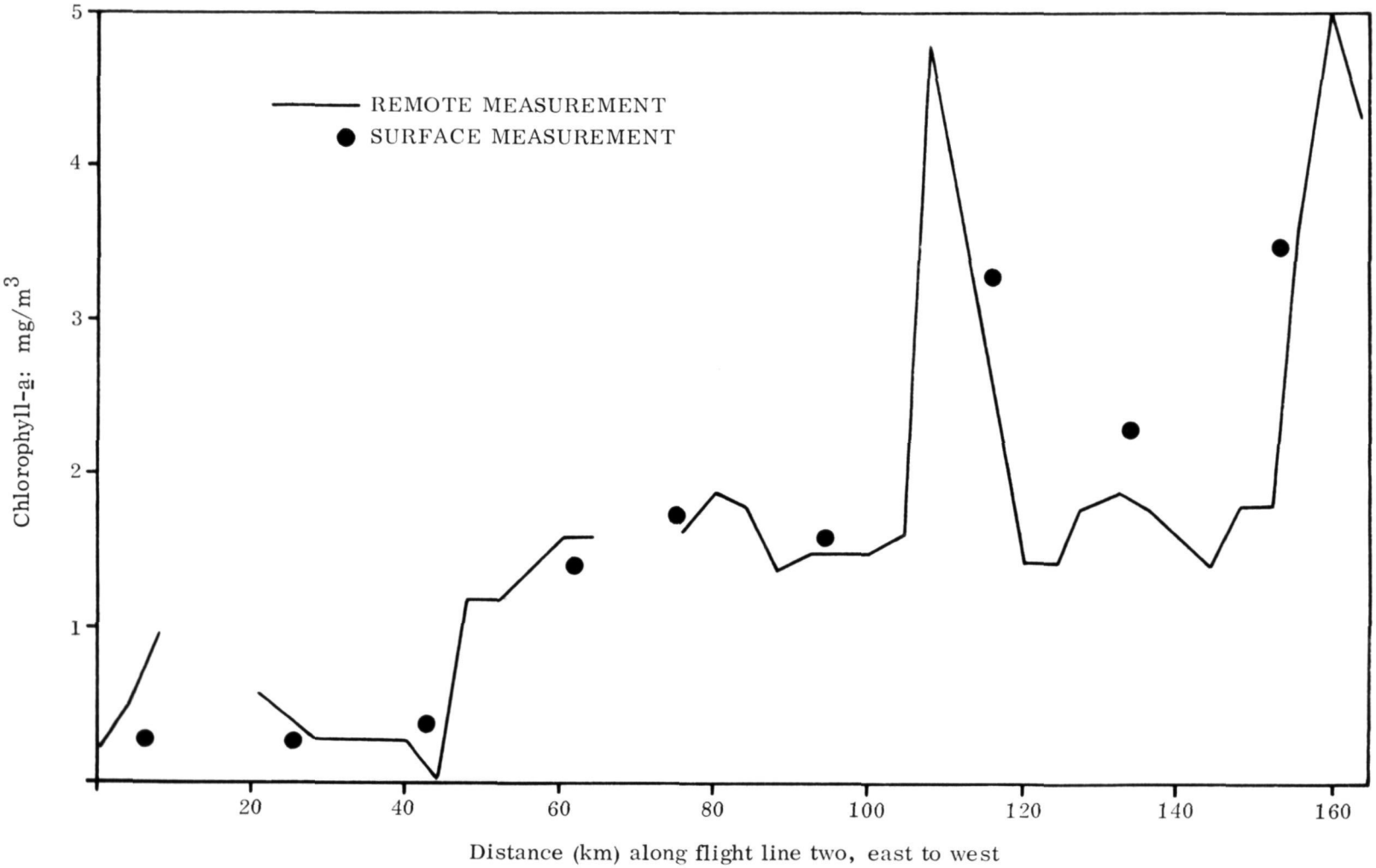


Figure 10. Comparison of Chlorophyll-a Remote and Surface Measurement Profiles Along Flight Line Two

the gamefish experiment was notably unsuccessful. The failure of this previously verified technique is probably due to the fact that Weldon's work was done with measurements made in the Mississippi Sound where three meters is generally the greatest Secchi depth observed, as opposed to thirty in the Gulf. Several techniques were developed to infer turbidity measurements from the spectrometer data.

The final algorithm as in the chlorophyll calculation optimized the information content relative to the Secchi transparency measurement. This optimization was performed by selecting wavelengths which showed the highest correlation with the Secchi depth and the least correlation with each other. Unnormalized radiance data, radiance normalized by a wide band in the blue (390-430 nm) region, and radiance normalized by a wide band in the infrared (911-1073 nm) region were examined. The best set of correlations was found with three wavelengths (410, 440, and 550 nm) of the blue-normalized radinace. An expression of the form

$$S_c = \sum_{n=1}^{3} \alpha_n R\lambda_n / R_{blue} + \alpha_4 \qquad (c)$$

was used to calculate the Secchi extinction depth.

The results are in agreement with the surface measurements as can be seen from Figures 11 and 12 which are contour maps of the Secchi extinction depth made from surface and remote measurements according to this technique. While the calculated rms error was 3.9 meters for 20 points, of which eight were used for calibration, the trends were well represented. The chief discrepancy between the two is in the area where surface readings on the order of 30 meters were made and where the remote measurement indicates greater turbidity.

There are two likely explanations for this variation. Because of the criteria used in selecting calibration points for the remote measurements, which included a maximum time difference between surface and remote measurements of three hours, no calibration points had Secchi depths of more than 17 meters. This would introduce an uncertainty of unknown magnitude into measurements outside the calibrated range. Also, reports from the surface observers indicated that water conditions were changing over the test area. It is thus possible that the sea conditions changed at this sample station during the four hour interval separating surface and remote measurements.

Salinity

Because salinity is an important factor in the white marlin predictor to be described later, it would have been desirable to use remote measurements of salinity in this experiment. The feasibility of applying L-band radiometer data to measure salinity remotely has been demonstrated by Thomann (19). Unfortunately, the microwave radiometer necessary for this measurement was not available for use on the aircraft for this experiment; the other potential source for remote salinity measurements was the L-band radiometer on Skylab. Unfortunately the footprint of the instrument was almost as large in area as the entire test site, resulting in insufficient resolution.

RESOURCE AND REMOTELY SENSED DATA RELATIONSHIPS

Approach

Fishermen in search of gamefish consider, as a rule, the color of the sea as the primary indicator of good fishing grounds. The generally accepted theory is that the gamefish are found principally

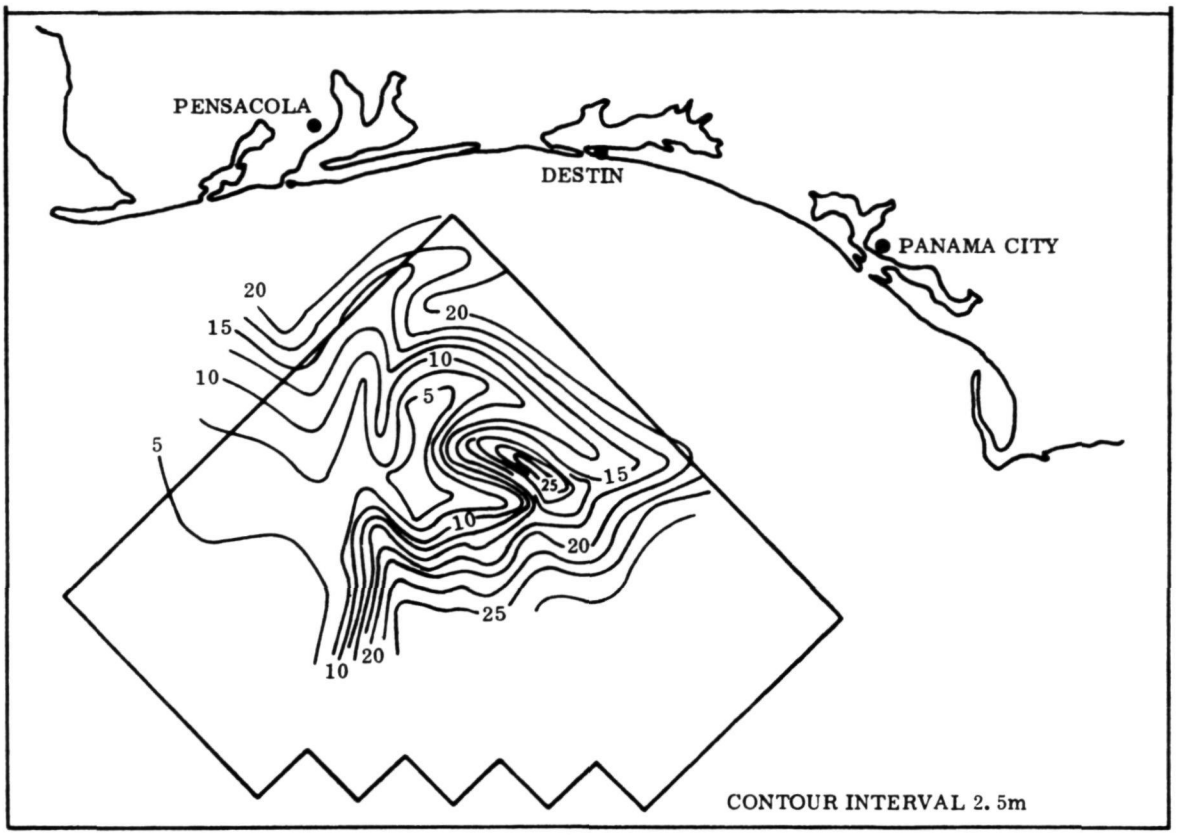


Figure 11. Surface Measurement of Turbidity (Secchi Extinction)

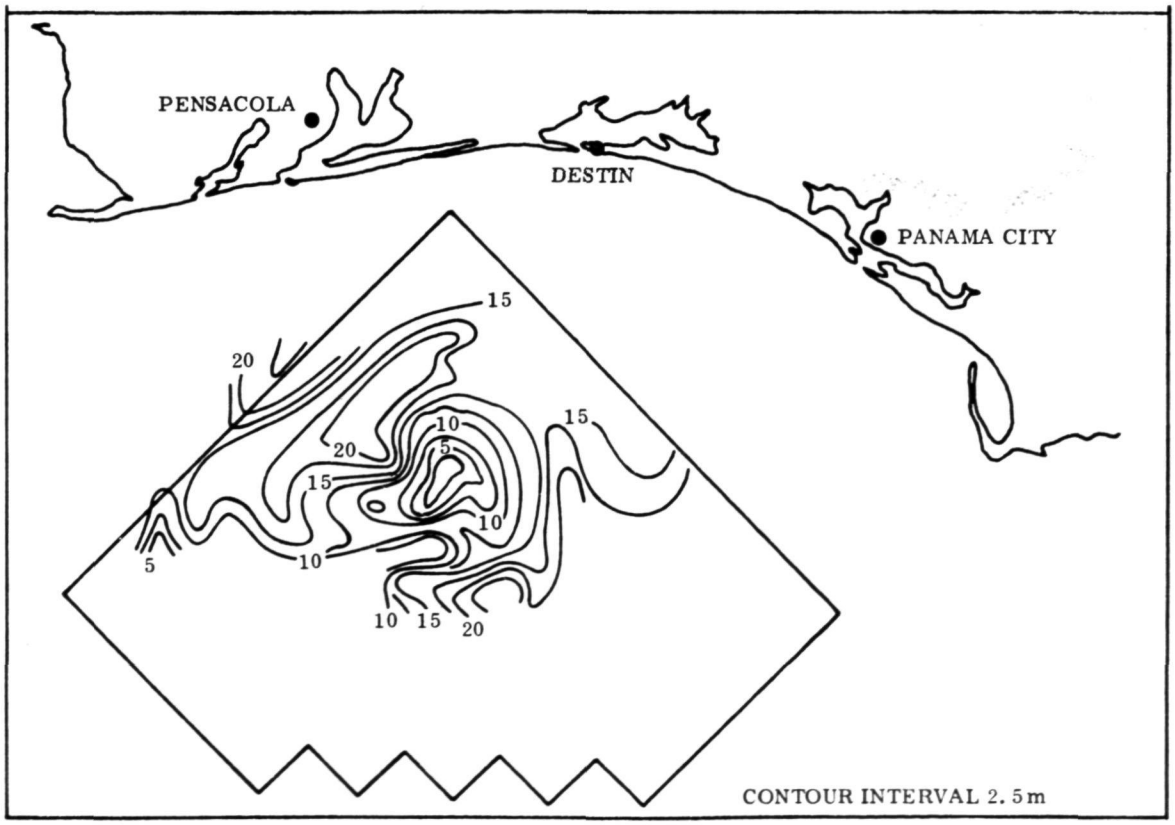


Figure 12. Remote Measurement of Turbidity

in areas where the water is blue as opposed to green. The approach taken in attempting to define a relationship between the billfish resource and marine phenomena directly sensible by the satellite and aircraft sensors utilized visual interpretation, color enhancement of multiband photography, and direct correlation between spectral radiometer "color" measurements and resource distribution information.

Water Discontinuities

The photography from the NC-130B and the light aircraft were visually examined for surface discontinuities which would indicate the boundary between different water masses. The discontinuities searched for were either sharp changes in water color, of which none were found, or surface rips. Many rips were identified, some in both sets of aerial photography. Unfortunately, the portion of the test site visible in the photography was small, therefore much of the study area could not be included in this analysis of the aerial photography.

Figure 13 shows the relationship between rips and white marlin hooked. The fishing squares containing rips are indicated by horizontal lines. Squares where fish were hooked are shaded. The limited data set does not permit any definitive conclusions to be drawn concerning fish/rip relationships, but one must observe that there are no fish caught in squares containing rips.

No rips were found in the Skylab S190A or S190B photography which has been examined in detail. This is to be expected since these surface features generally have widths less than the resolution of both the S190A and S190B sensors.

S190A Photographic System

The S190A multispectral photographic system consisted of six high-precision cameras with matched optical systems. Each had an F/2.8 lens with aperture variable to F/16 in 1/2-stop increments and a focal length of 15.2 centimeters (6 inches). At a nominal spacecraft altitude of 435 kilometers (235 nautical miles), the 21.2-degree square field of view provided ground coverage 163 kilometers (88 nautical miles)square. The film width was 70 millimeters, which provided a usable image 5.7 centimeters (2 1/4 inches)square. The camera system compensated for the forward motion of the spacecraft along the flight path. Each of the six cameras was identified by a station number and equipped with combinations of filters and films for the various wavelength bands (Table V).

Positive black and white transparencies of the experimental area for stations 1, 2, 5, and 6 and positive color transparencies for stations 3 and 4, scaled at 1:2,850,000 were received as S190A data products from NASA's Johnson Space Center.

Of the S190A film products acquired and received for analysis, black and white (B&W) 70 mm negative transparencies of successive frames 242 and 243 (11:41:04.3 CDT) of all six stations were made and used in density slicing/color enhancement analyses. Neither frame selected would accommodate the entire test area. Figure 14 shows the two frames from station 6 spliced together with the test site overlaid. Pensacola harbor may be seen in the upper right corner. The S190A photograph revealed a number of anomalous dark patches (20) within the sun-glint areas, the largest of which appeared in grid square numbers 31 and 48. This particular patch was oval shaped; it encompassed a total area of about 570 square kilometers and was associated with calm sea state measurements ranging from 30 to 40 cm.

Initially, two bands, 0.5 - 0.6 μm and 0.6 - 0.7 μm were density sliced to derive sea surface

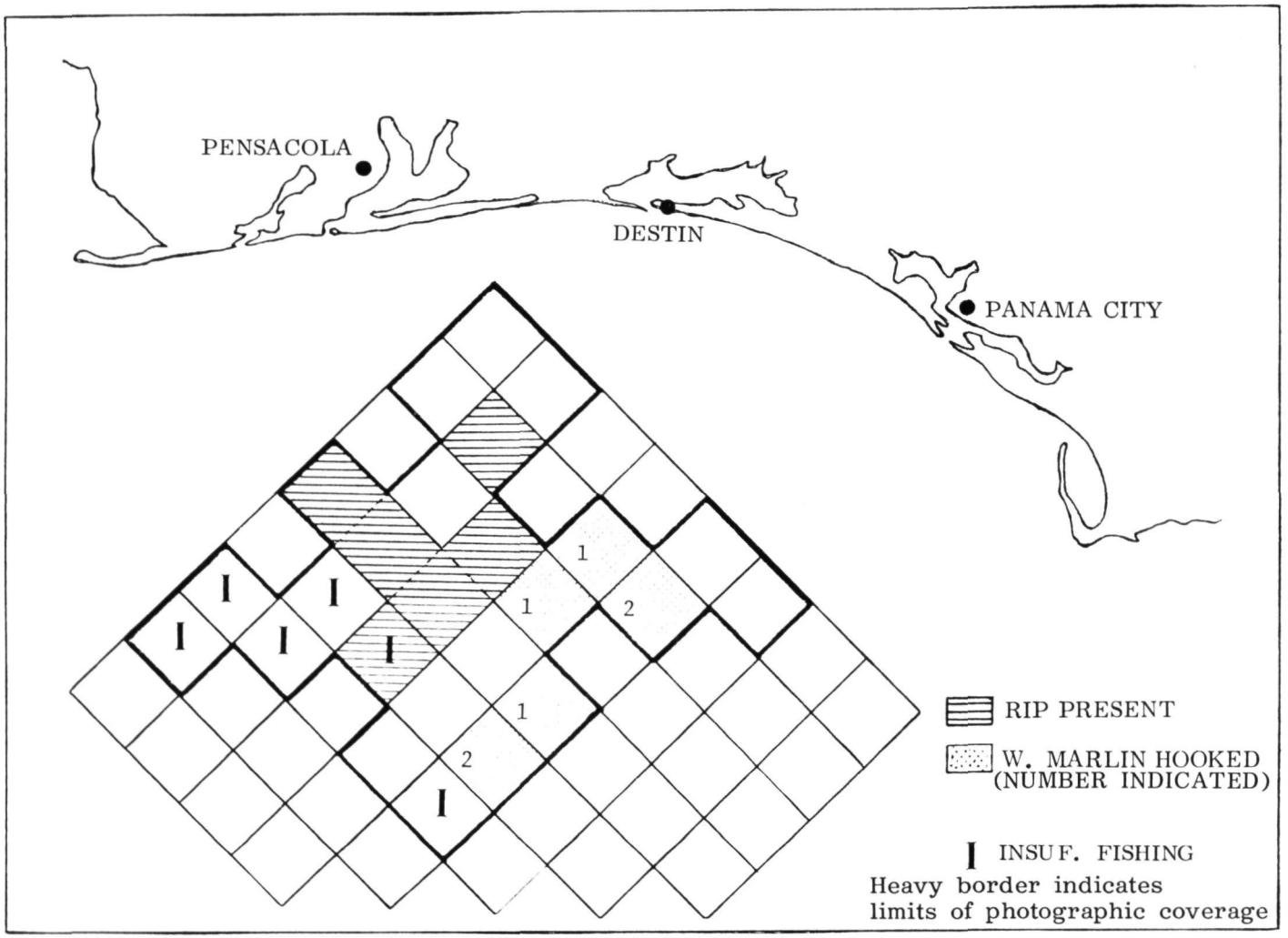


Figure 13. Comparison of White Marlin Distribution with Surface Rip Locations

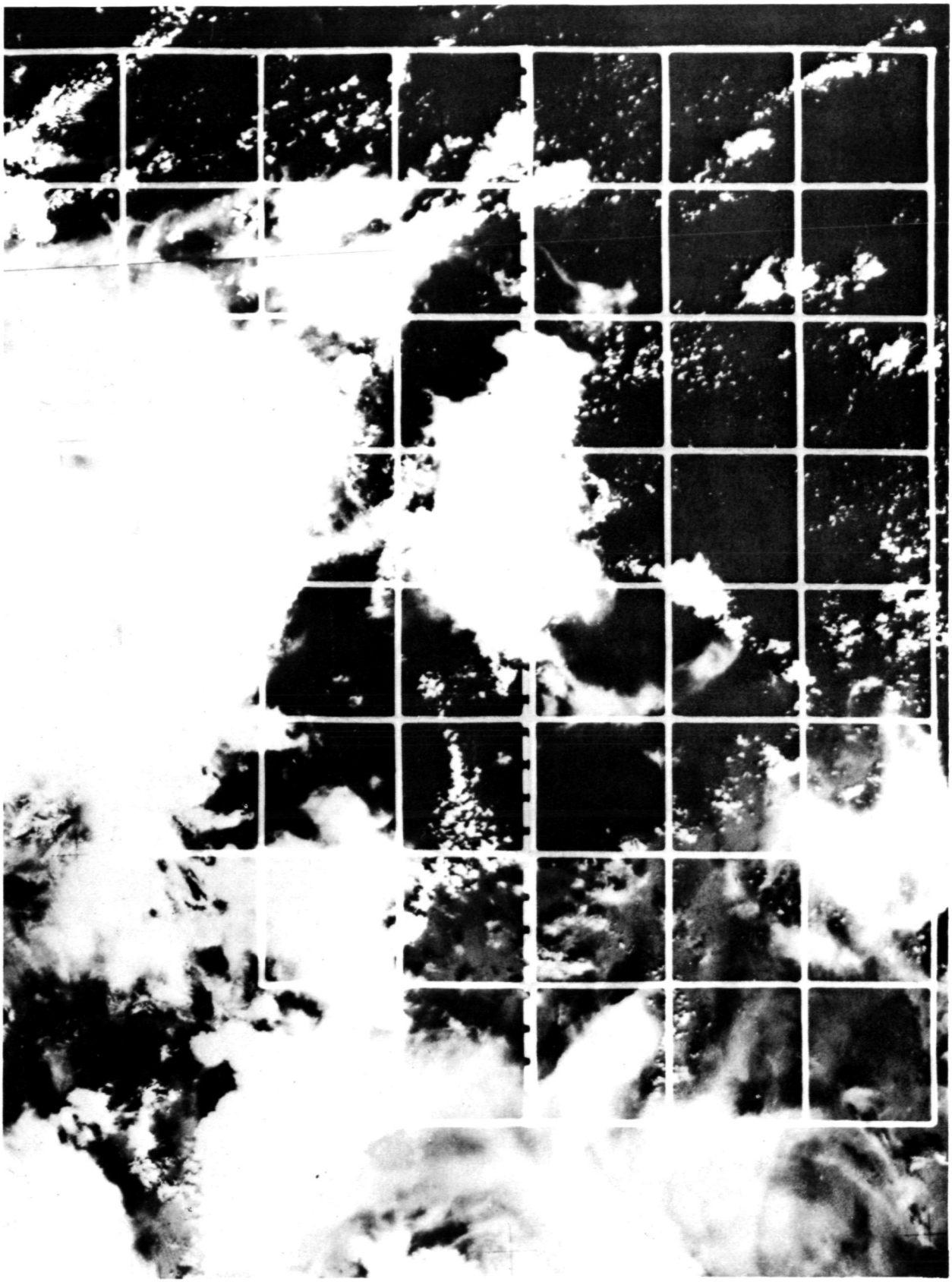


Figure 14. S190A Photography with Test Site and S191 Ground Track Overlay

TABLE V. MULTISPECTRAL CAMERA STATION CHARACTERISTICS

AND FILM ROLLS USED

Sta	Filter	Filter Bandpass, micrometer	Film Type*	Estimated Ground Resolution // meters (feet)	Mission SL-3 Roll No.
1	CC	0.7 - 0.8	EK 2424 (B&W infrared)	73 - 79 (240 - 260)	19
2	DD	0.8 - 0.9	EK 2424 (B&W infrared)	73 - 79 (240 - 260)	20
3	EE	0.5 - 0.88	EK 2443 (color infrared)	73 - 79 (240 - 260)	21
4	FF	0.4 - 0.7	SO-356 (hi-resolution color)	40 - 46 (130 - 150)	22
5	BB	0.6 - 0.7	SO-022 (PANATOMIC-X B&W)	30 - 38 (100 - 125)	23
6	AA	0.5 - 0.6	SO-022 (PANATOMIC-X B&W)	40 - 46 (130 - 150)	24

* Eastman Kodak Company // At low contrast

information. Comparing the distribution of hooked white marlin per square with the image sliced into five density levels revealed that fish were hooked in squares having different density levels. The fishery resource data, as summed and positioned to the center of the squares, therefore could not be correlated with any particular density slice of the S190A multiband Skylab photography as originally anticipated.

Further efforts were made to get by this deficiency by utilizing white marlin catch locations accurately to 1/2 mile (twelve in number) determined by electronic navigation equipment aboard a subset of fishing vessels participating in the experiment. A re-examination of the imagery from stations 1 through 6 was made to determine if the distribution of white marlin was located in a particular density region. The image in Figure 14 was density sliced and color coded on a VP-8 image analyzer. The white marlin locations were superimposed and the resulting image photographed and displayed in Figure 15.

Stations 4 and 6 provided better water detail than the other stations, but as can be seen from Figure 15, no density/white marlin relationship could be established. This does not imply that such a relationship does not exist but only that utilizing this set of fishery data and this set of multiband photography, with band widths previously stated, no relationship could be established. More work is needed in this area of analysis in terms of establishing exact location of the fish, and using S192 data with its narrow-band imaging within the 0.4 to 0.7 µm region and a thermal band as well as digital density slicing and color enhancement techniques to determine if indeed a relationship exists.

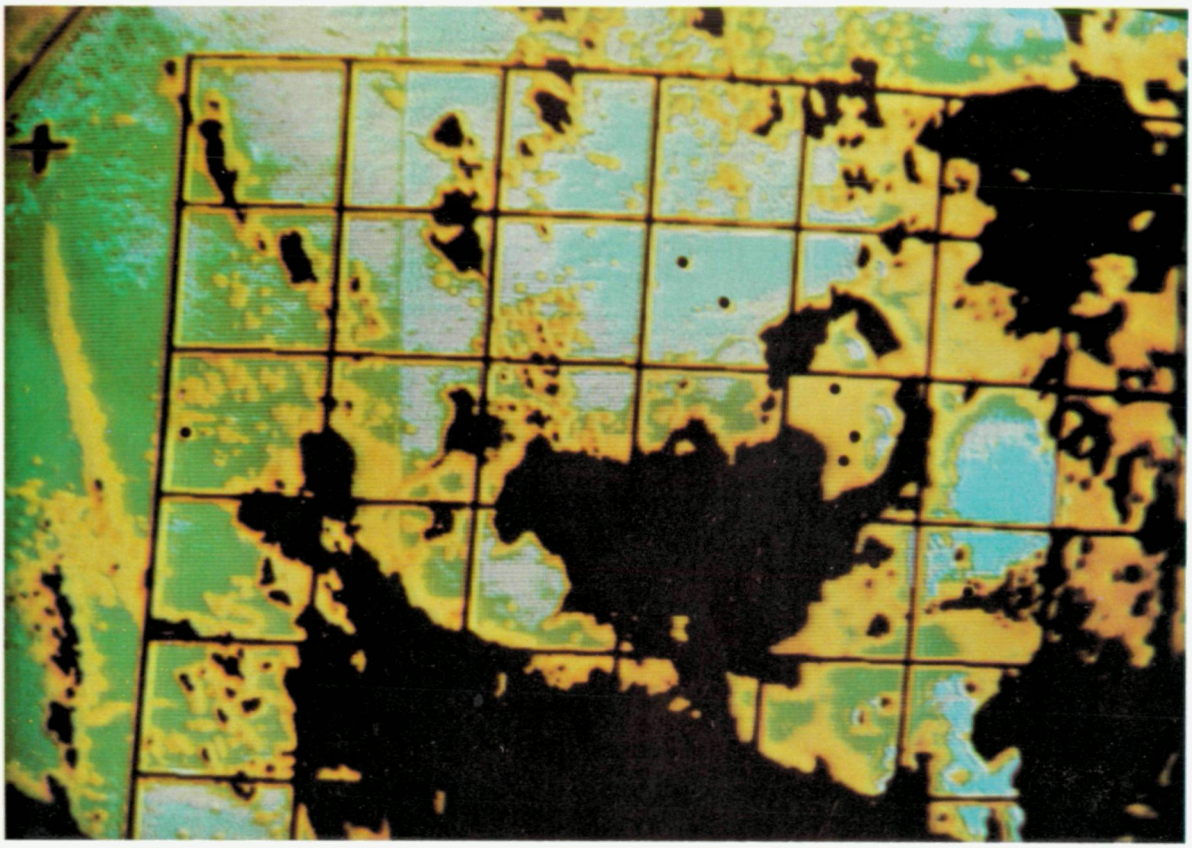


Figure 15. S190A Photography Density Sliced and Color Enhanced with Test Site and White Marlin Locations Superimposed

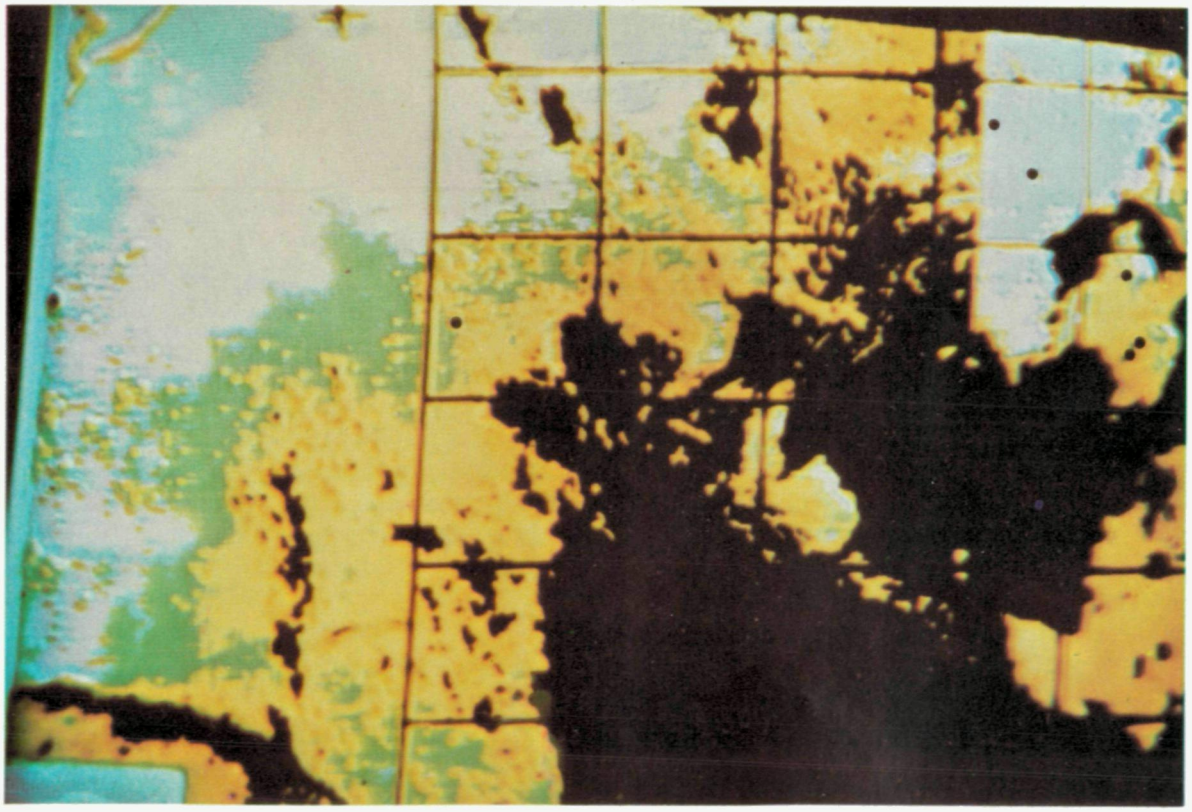


Figure 16. S190B Photograph Density Sliced and Color Enhanced with Test Site and White Marlin Locations Superimposed

S190B Photographic System

The S190B earth terrain camera was a single-lens camera assembly having an F/4 lens with a focal length of 45.7 centimeters (18 inches). The camera system was compensated for Skylab's forward motion and had a field of view of 14.24 degrees which produced a square ground coverage of about 109 kilometers (59 nautical miles). Film width was 12.7 centimeters (5 inches), which provides a usable image 11.4 centimeters (4.5 inches) square. On this particular mission, SO-242 (high resolution color) film was used. The filter bandpass was 0.4 - 0.7 µm and the estimated ground resolution at low contrast was 21 meters (70 feet).

Positive color transparencies of the test area approximately 22.86 x 22.86 cm (9 x 9 inches) scaled approximately 1:500,000 were received as S190B data products from NASA's Johnson Space Center.

Negative black and white transparencies from frames 220 and 221 which were spliced together and reduced to approximately 22.86 x 11.43 cm (9 x 4 1/2 inches).

A transparent overlay, containing the test area and that set of white marlin catch locations which could be located to within one-half mile, was prepared and utilized in the density slicing color enhancement analysis as shown in Figure 16 on the previous page.

The clouds (highest reflected radiance) are colored black and sun-glint areas orange. Sun-glint covers a large area in the lower right hand side of frame 220. Water areas were density sliced into three regions and assigned the colors of green, purple and blue going from highest reflected radiance to lowest reflected radiance. Again no relationship between the density of reflected light in the 0.4 to 0.7 µm range and white marlin distribution could be established from a visual evaluation. Sample size of 8 white marlin locations which could be located to .804 km (1/2 mile) accuracy and fairly clear of cloud cover was somewhat small, therefore no attempt was made to compute statistical correlation between fish location and radiance density values.

One promising aspect of the S190B imagery not a part of this experiment was the fact that several of the sportfishing boats could be seen with the naked eye. The fishing boat shown in Figure 17 is 12.5 meters (38 feet) long and was identified by time/position information taken from fishing logs. While the estimated ground resolution of the S190B at low contrast was approximately 21 meters (70 feet), this high contrast target of 12.5 meters (38 feet) shows up quite vividly. From the logs, it could further be established that boats less than 8.9 m (27 feet) could not be seen.

S191 System

The S191 sensor is made up of three major elements - a Cassegrainian telescope and plane-mirror optical system that provided an image of the scene to the other two elements, a filter-wheel spectrometer that scanned the radiation from the scene and a boresighted viewfinder and tracking system with the same line of sight as the spectrometer. The infrared sensor's instantaneous field of view was approximately .435 kilometers (.235 nautical mile) in diameter. Incoming radiation was split into short and long-wavelength bands; 0.4 to 2.5 micrometers and 6.6 to 16 micrometers.

Examination of the S191 data acquired over the test area during the Skylab/Gamefish Experiment has revealed that cloud cover obscured major portions of the sensor's coverage along the flight track. This is shown in the S190A station 6 (0.5 - 0.6 µm) imagery with the test site and S191 ground track superimposed. (Figure 14). An isometric presentation of the data from the short wave band (0.4 to 1.1 µm) of the S191 sensor is shown in Figure 18. This presentation of the data

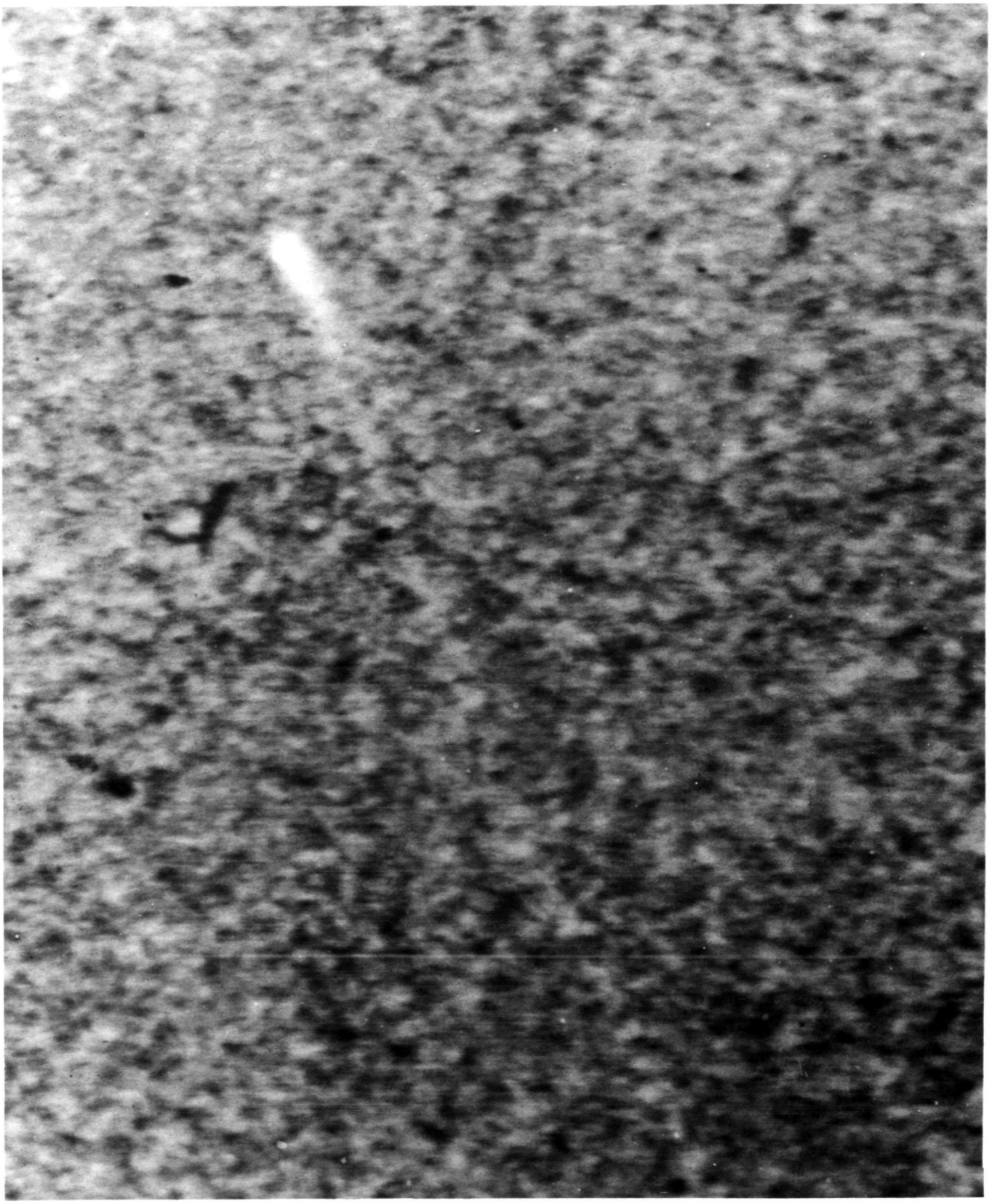


Figure 17. S190 Photograph of Sport Fishing Vessel Magnified 50 Times

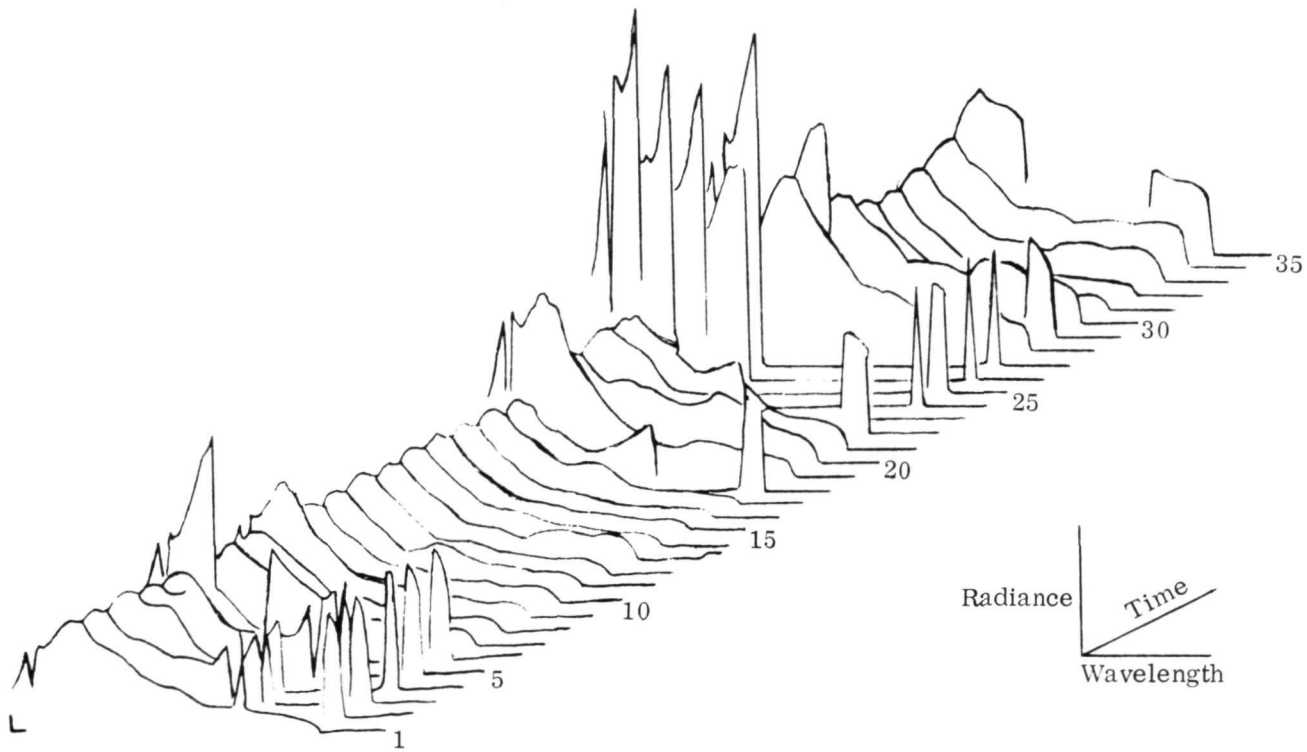


Figure 18. The Isometric Presentation of the Visible Portion of the S191 Spectra

represents the information from channel A3, the high gain silicon detector. When the channel saturates, a value of zero is indicated, so when the spectrometer was viewing the very bright clouds and the signal was saturated, the spectrum indicates a zero radiance. Spectra 13 through 35 were taken very near or over the test area. Surface sampling stations were located in areas sampled by the S191 as spectra 13, 15, 18, 20, 22, 25, and 27. Spectra 13 through 15 were cloud free, while spectrum 18 indicates saturation in one portion of the spectrum, due most likely to a small cloud which entered the sensor field of view only briefly. Spectra 19 through 21 appear contaminated, but not saturated. Spectra 22 through 27 are saturated. The rest of the spectra are all contaminated. This limited set of sensor data has prevented further analysis such as development of predictive algorithms for chlorophyll-a and turbidity based on selected S191 spectra.

In addition, initial plans to compute radiance values every 50 nanometers from 0.4 to 0.7 µm range for each 8.05 km (5 mile) subsquare crossed by the S191 flight track resulted in data for only one subsquare. This prohibited any type of statistical analysis between the white marlin distribution and data from this sensor.

S192 Multispectral Scanner

The multispectral scanner was an optical electromechanical scanner which collected incoming radiant energy using a rotating mirror in the image plane to conically scan the scene viewed. The energy scanned in the image plane passed through a reflective Schmidt corrector mirror and through a field stop that was the entrance slit of a prism spectrometer. The short wavelengths (0.41 to 2.43 micrometers) were separated from the long thermal wavelength band (10.2 to 12.5 micrometers) by a dichroic mirror. The spectrally dispersed electromagnetic energy received from the scene irradiated thirteen detectors simultaneously. Detectors and associated wavelengths are listed below:

Band No.	Wavelength, Micrometers
1	0.41 - 0.45
2	0.44 - 0.52
3	0.49 - 0.56
4	0.53 - 0.61
5	0.59 - 0.67
6	0.64 - 0.76
7	0.75 - 0.90
8	0.90 - 1.08
9	1.00 - 1.24
10	1.10 - 1.35
11	1.48 - 1.85
12	2.00 - 2.43
13	10.20 - 12.50

Each detector produced an electronic signal that corresponded to the average value of the radiance received in its spectral band from the spot on the surface in the instrument's 0.182 milliradian field of view. The field of view of each detector provided an instantaneous square ground coverage of 79 meters (260 feet) swept in a conical scan. The ground swath width of the sensor was 74 kilometers (40 nautical miles).

Black and white 12.7 centimeter (5-inch) film images of corrected/filtered data from bands 1-13

and digital data on tapes from bands 1-9 and 13 have been received from NASA-JSC. Evaluation of the S192 imagery resulted in the identification of a ringing of cloud edges across the cloud free areas of the imagery in bands 3, 4, 5, and 8. Discussions with NASA have confirmed that the high frequency filtering of the data created this distortion as shown in Figure 19. Distortion can be seen on both sides of the shoreline as waves and out further in the frame as cloud edge duplication. Band 2 is very noisy with frequent scan line dropout. Band 13 is also very noisy.

A request to reprocess bands 1-9, and 13 without high frequency filtering in bands 1-5, 7 and 8 has been submitted to the NASA. Further analysis of this set of data is pending receipt of data.

PREDICTION MODELS

Model Development

Multiple regression analysis was used to develop models to predict white marlin distribution ($\bar{D}$) in the Skylab test area. Initial runs utilized the eleven parameters listed in Table IV along with all possible interactions (formed by computing the products of each parameter pair) as the independent parameters. The first models D_1, D_2, D_3 listed in Table VI were constructed utilizing data collected on 4 August, on 5 August, and the combination of 4-5 August. These models were developed based on five parameters: surface water temperature (T), Secchi extinction depth (C), salinity (S) and the two interaction parameters, the product of Secchi extinction depth and chlorophyll-a, (CA), and the product of salinity and surface water temperature (ST). Comparison of constant terms and coefficients (by magnitude and sign) in models D_1, D_2, and D_3 reveal extreme difference or instability from day to day. Therefore, it appeared that important information was not considered, a combination of linear terms was not sufficient to model the day to day changes, or a white marlin distribution model could not be developed.

Additional work was initiated to try to stabilize the models. Water density was computed and substituted for the product of water temperature and salinity. The latter two had been used in the earlier regression runs. A measure of water density (σ_t) was computed utilizing the following equations (21).

$$C1 = \frac{S-0.030}{1.805} \qquad \text{(d)}$$

$$\sigma_o = -0.069 + 1.4708\ C1 - (1.57 \times 10^{-3})\ C1^2 + (3.98 \times 10^{-5})\ C1^3 \qquad \text{(e)}$$

$$\Sigma_t = -\frac{(t-3.98)^2}{503.57} \cdot \frac{t+283}{t+67.26} \qquad \text{(f)}$$

$$A_t = t\left[4.7867 - 0.098185t + (1.0843 \times 10^{-3})t^2\right] \times 10^{-3} \qquad \text{(g)}$$

$$B_t = t\ (18.03 - 0.8164t + 0.01667t^2) \times 10^{-6} \qquad \text{(h)}$$

$$\sigma t = \Sigma_t + (\sigma_o + 0.1324)\left[1 - A_t + B_t\ (\sigma_o - 0.1324)\right] \qquad \text{(i)}$$

where: S = salinity in $^{o}/oo$
t = temperature in ^{o}C
σ_t = density parameter

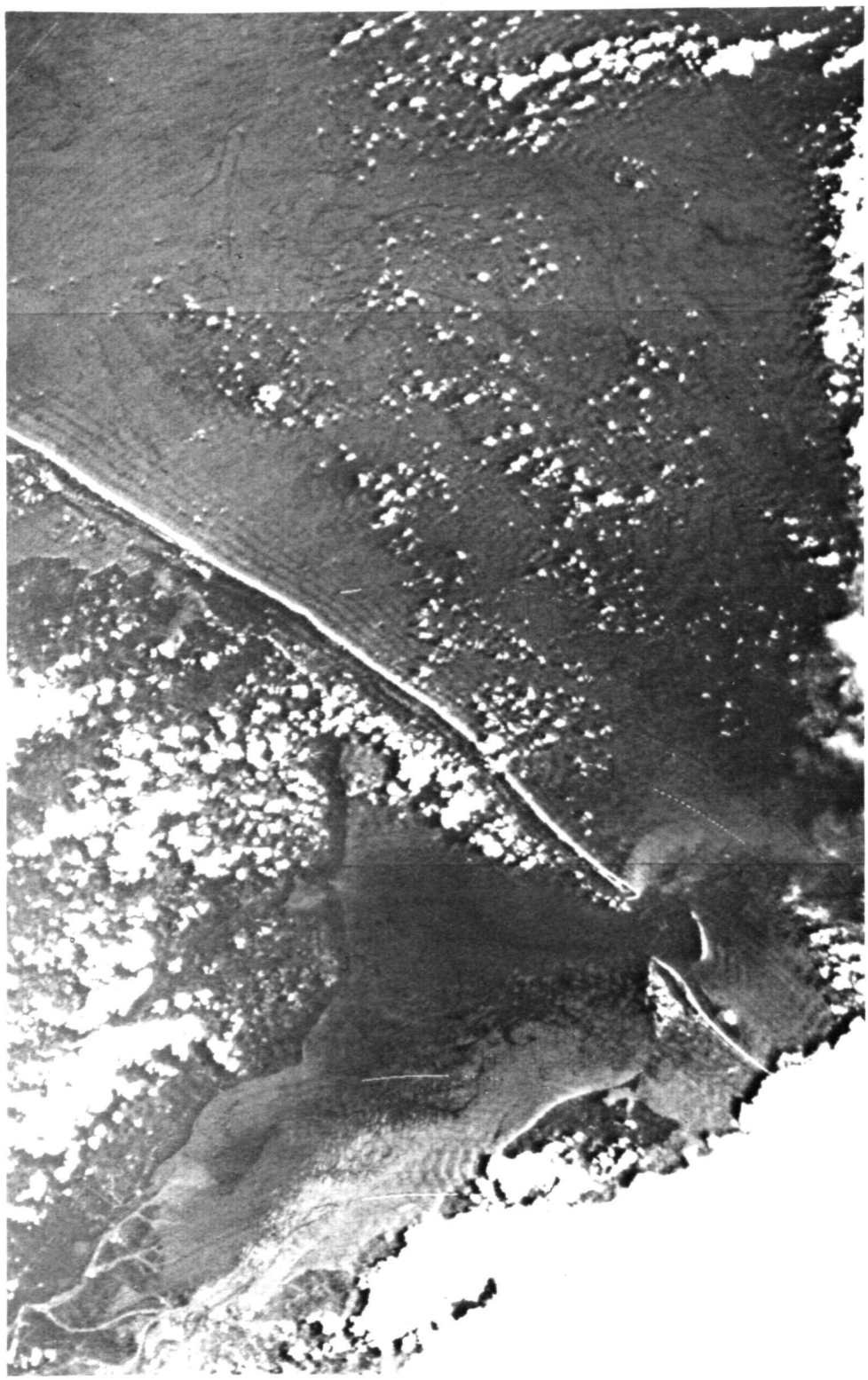


Figure 19. Imagery of Part of the Test Area Taken from Band 3 of the S192 System

TABLE VI. EMPIRICAL REGRESSION MODELS WHICH PREDICT WHITE MARLIN (D) IN THE SKYLAB TEST AREA

T = Water temperature (°C)
C = Secchi disc transparency (m)
S = Salinity (ppt)
ST, CA = Interaction formed as the product of the respective parameters

B = σ_t (measure of water density)
where $\sigma_t \times 10^{-3} + 1$ = water density (g/cm^3)

A = Chlorophyll-a (mg/m^3)

MODEL	INCLUSIVE DATES (1973)	n	REGRESSION MODEL	STANDARD ERROR OF $\bar{D}$	MODEL CORRELATION COEFFICIENT	SIGNIFICANCE LEVEL (%)
D_1	4 August	24	$\bar{D}$ = -419.5394 + 14.3929T +12.9764S + .0567C -.4461ST + .0074CA	0.3435	0.797	99.5
D_2	5 August	22	$\bar{D}$ = 164.1002 - 5.3527T -6.3246S + 0.173C +.2071ST - .0021C	0.4996	0.499	50
D_3	4 & 5 August	46	$\bar{D}$ = -25.4052 + .9301T +.3258S + .0139C -.0133ST + .0008CA	0.4751	0.436	75
D_4	4 August	24	$\bar{D}$ = -13.3676 + .6583T +.0718C + .3651B +.0043CA	0.3589	0.762	99.5
D_5	5 August	22	$\bar{D}$ = -22.4714 + .8179T +.0143C -.1035B -.0014CA	0.4879	0.489	60
D_6	4 & 5 August	46	$\bar{D}$ = -12.8553 + .4959T +.0142C - .0950B +.0007CA	0.4693	0.436	90

NOTE: Water density (g/cm^3) at observed salinity temperature and 0 meters depth (atmospheric pressure) = $\sigma_t \times 10^{-3} + 1$.

The resulting density measure σ_t was used in constructing models D_4, D_5 and D_6 which also contain surface water temperature, Secchi extinction depth, and the product of Secchi extinction depth and chlorophyll-a. Comparison of the constant term and coefficients reveals a significant improvement in the stability of coefficient of each parameter from model to model. It should also be noted that the significance level was improved on models D_5 and D_6. The result indicates that the relationship between white marlin distribution and the environmental parameters is more complex than a linear combination of the environmental parameters. However, while only two days of data were available for modeling efforts, it is evident that the relationship can be modeled with reasonable stability from day to day.

Model Evaluation

The D_4 and D_5 models were tested with independent test data by using 4 August test data in D_5 (developed from 5 August data) and 5 August test data in D_4 (developed from August 4 data). In each case the resulting unnormalized predicted distribution values (Y) were separated into low, medium, and high probability ranges. This was accomplished by computing the mean ($\bar{Y}$) and standard deviation (S) of each set of predicted values. The probability ranges were fixed as follows:

$$\text{Low probability} = Y < \bar{Y} - 1/2\ S$$

$$\text{Medium probability} = \bar{Y} - 1/2\ S \leq Y \leq \bar{Y} + 1/2\ S$$

$$\text{High probability} = Y > \bar{Y} + 1/2\ S$$

Each predicted value for each test square was classified as low, medium, or high depending on the probability range in which it fell. The actual distribution value for each test square was assigned a high probability if it had a distribution value of 1 and a low probability if it had a distribution value of 0.

Nine of 24 fishing squares were classified as medium probability areas. Actual fish catch in those nine squares revealed that there existed a 50 percent chance of being in an area that had fish. Considering the extreme of low and high probability regions for model evaluation as shown in Table VII, the model was 93 percent accurate in predicting fish location in the remaining 15 squares.

TABLE VII. EVALUATION SUMMARY FOR 4 AUGUST PREDICTED VALUES USING MODEL D_5

Actual	Predicted	Number of Test Squares
HIGH	HIGH	5
LOW	LOW	9 = 93% correct
LOW	HIGH	1
HIGH	LOW	0 = 7% incorrect

Ten of the 24 squares fished produced fish-catch results which revealed that a fisherman had a 42 percent chance of being in a location having fish if a square was randomly selected from the 24 squares. However, if a fisherman selected one of the six predicted high probability squares his chance of being in area having fish increased to 83 percent.

To further determine the value of the predicted high probability squares, an evaluation of these squares with associated abundance data was made. It was found that in the six squares selected by Model D_5 from 4 August data or 25 % of the test area, 67% of the white marlin were hooked in 31% of the fishing time.

Visual representations of the predicted values from model D_5 is shown in Figure 20. The number of predicted test squares within a given range having fish are denoted by the shaded areas or solid lines. The number of predicted test squares within a given range not having fish are denoted by the dash lines. Ideally the shaded areas should cluster near the high value or high probability portion of range and the dash line areas near the low value or low probability portion with a very minimum of intersection. The results shown in Figure 20 tend toward the ideal conditions.

The analysis of 4 August data utilizing model D_5 demonstrates the potential for reducing a fishing area by identifying high probability areas. For the cases in point a factor of three or four would be achieved. Furthermore, by only considering high probability areas, the overall probability of being in an area where fish may be hooked, can be increased approximately by a factor of two in the case discussed.

MODEL TESTING OF AIRCRAFT REMOTELY SENSED DATA

Data values for remotely sensed sea surface temperature, chlorophyll-a and turbidity were selected from the applicable contour maps. No remotely inferred values for salinity were available so sea truth salinity measurements were used. Water density was computed for each square using remotely sensed temperature and the sea truth salinity. The data values were substituted in Model D_5 and the predicted white marlin distribution values which resulted, were classified as low, medium or high probability areas according to the procedure given in Model Evaluation. Again, not considering the predicted medium probability squares (8 in number) the resulting evaluation is shown in Table VIII. The results are probably indicative of errors occurring in one or more of the following processes.

- Selection of data from hand contoured charts of remotely sensed data.
- Use of actual distribution comparison values based over the entire day rather than the plus or minus two hours of the aircraft flight time.
- Extrapolation of values from the narrow footprint coverage of the aircraft sensors.

TABLE VIII. EVALUATION SUMMARY FOR 5 AUGUST PREDICTED VALUES USING MODEL D_5 WITH REMOTELY SENSED VALUES

Actual	Predicted	Number of Test Squares
LOW HIGH	LOW HIGH	2 1 = 50% correct
LOW HIGH	HIGH LOW	2 1 = 50% incorrect

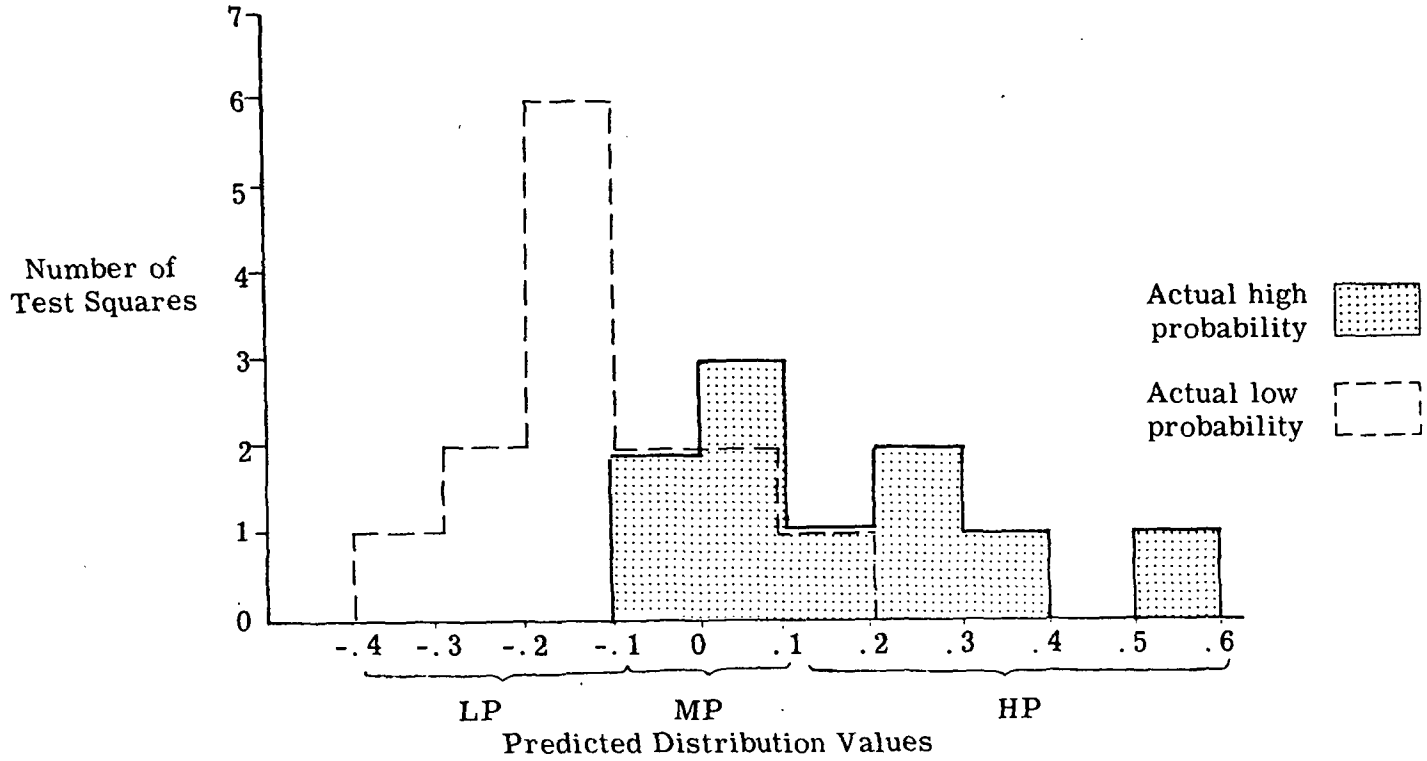


Figure 20. Evaluation of August 4 Predictions, Using August 5 Model D_5

Application

Oceanic gamefish distribution prediction models of the type reported herein would clearly serve sportsfishermen and resource managers. Knowledge of highest potential catch areas as a function of time will provide sportsfishermen with the benefits of increased catch and decreased time and fuel expenditures. Figure 21 is an example of a prediction model product which displays fishing areas in terms of catch potential.

These prediction models are presently not adequate for resource management applications. Daily operational utilization of these models must wait until techniques for remotely sensing the necessary environmental parameters become fully functional on a synoptic basis.

As models are improved to an acceptable precision level and as repetitive data acquisition becomes economically feasible, it is reasonable to presume that these or similar models could provide the abundance and distribution information necessary for development of conservation and harvesting procedures. As operational readiness and confidence in such models are established, resource managers would have additional information on which to base domestic and international conservation decisions.

Application to Wide Areas

Considerations relative to the application of the model to wide areas may be categorized as both spatial and temporal. The parameters used in the model were selected because they applied significantly to the white marlin resource in the Gulf of Mexico during the time frame of data acquisition. Elsewhere in the world, for other species and possibly different time frames, other parameters might figure more importantly. The models would require rework using the parameters most applicable to the particular area or possibly using the same set with additional parameters representing the unique, environmental characteristics identified with that area.

The relatively narrow range of values used in model development is another factor presently limiting use elsewhere except where the environment is analogous to that of the Gulf of Mexico during the month of August. For example, the sea truth measurement of sea surface temperature varied from 28.5°C to 31.6°C during the data acquisition operations. For temperature values outside that narrow band, it is unclear if the model performance would be adequate. This is true about each parameter.

The models are based on data taken during the limited, two day operations and which covered a very small portion of the total range of each parameter. It is questionable how well the model would function with data outside the range of the data with which it was developed. However, since parameter range is obviously associated with seasonal weather (except in the tropics), model inadequacy with respect to data range may be considered a temporal deficiency which could be corrected by the input of additional data collected during other seasons of the year.

The model could be tested elsewhere than in the Gulf of Mexico to resolve the question of spatial deficiency. For example, white marlin are fished quite heavily along the southern Atlantic Coast which could be used as second test area from which to collect data. Future investigations could well include both temporal and spatial testing of the relationship between white marlin and the environment.

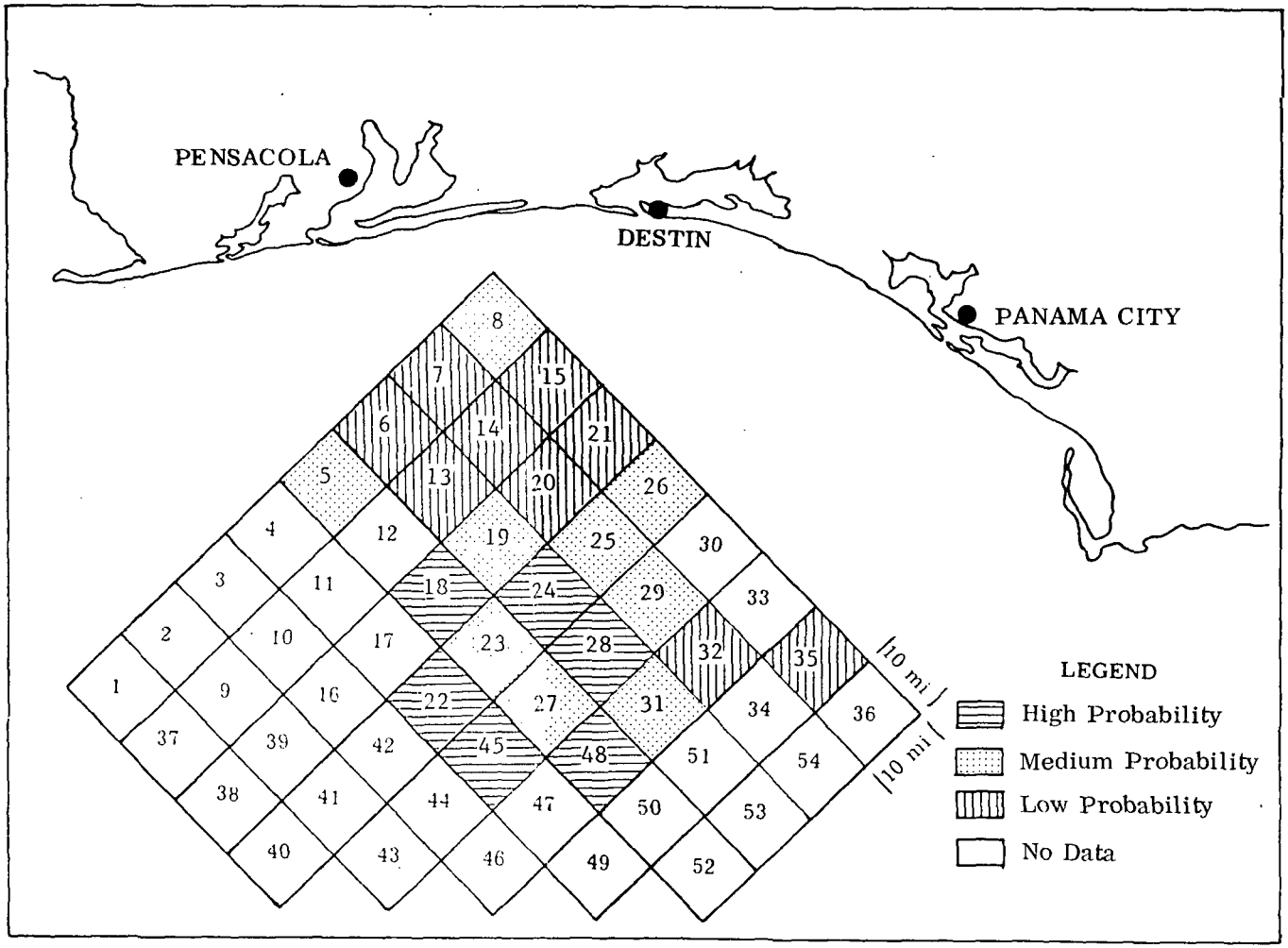


Figure 21. Prediction Results of August 4 Data Using Model D_5

CONCLUSIONS

The distribution and abundance of white marlin correlated with sea truth measurements. Correlation analyses were also done for dolphin, but the results were inconclusive.

Prediction models for white marlin were developed which demonstrated a potential for increasing the probability of game-fishing success. They also demonstrated a potential for reducing a sportsman's search time significantly by identifying areas which have a high probability of being productive.

Chlorophyll-a, sea surface temperature and turbidity (Secchi extinction depth) values were inferred from aircraft sensor data. Comparisons with sea truth measurements indicate that, in spite of sometimes unfavorable atmospheric conditions, reasonable accuracy can be expected.

Cloud cover and sun-glint in the test area on August 5, 1973, inhibited the usefulness of the Skylab S190A and S190B imagery. The S190A and S190B imagery was density sliced/colored enhanced with white marlin location superimposed on the image, but no density/white marlin relationship could be established. The resolution of the S190B system was sufficient to see fishing boats 12.5 meters (38 feet) in length. This demonstrated a potential use in fishery remote sensing surveillance systems. S191 data are insufficient for detailed fishery analysis. The S192 multispectral data were evaluated and a significant problem associated with high frequency filtering was identified. Detail analysis of these data, with respect to the fishery resource data, was delayed until this problem can be corrected. Because of these factors, it remains unclear if data from satellite sensors can be used in models to predict gamefish abundance and distribution. However, with the successful identification of the fisheries significant oceanographic parameters and the demonstration of the capability of measuring most of these parameters remotely, the first step toward establishing the feasibility of utilizing remotely sensed data to assess and monitor the distribution of oceanic gamefish was accomplished.

ACKNOWLEDGEMENTS

The Skylab Oceanic Gamefish Project was a lengthy, multidisciplined experiment entailing an extensive data gathering operation followed by a complex and detailed data analysis phase. In any such experiment it is difficult to focus on individual efforts. However, each role was important and the Principal Investigator gratefully acknowledges the efforts of the many participating organizations and individuals who contributed to the experiment.

Sportsfishermen provided gamefish data resulting from participation in a tournament coordinated through the Pensacola Big Game Fishing Club by a committee of anglers representing four big gamefishing clubs and two charterboat associations. The committee members were Mr. G. Arnold III, Mobile Big Game Fishing Club, Mr. Bill Bacon, Destin Charter Boat Association, Mr. M. Claverie, Jr., New Orleans and Golden Meadow Big Game Fishing Clubs, Dr. F. T. Neth, Pensacola Big Game Fishing Club and Mr. B. J. Putnam, Panama City Charter Boat Association. Another contribution from the sportsfishing community was the use of facilities at check point marinas at Pensacola, Destin and Panama City, FL, during field operations.

The National Aeronautics and Space Administration's (NASA) Lyndon B. Johnson Space Center (JSC), Houston, TX, directed the activities of the Skylab astronauts during overpass, provided the earth survey aircraft, the NC130B, to overfly the test site, and contracted the experiment. The NASA National Space Technology Laboratory (NSTL), Bay St. Louis, MS, provided extensive laboratory, field site and public relations support. The NASA contractors at NSTL, the General Electric Company and Lockheed Electronics, Inc., assisted with field and technical support.

The NASA JSC Earth Resources Laboratory (ERL) located at the NSTL was responsible for the planning, acquisition and processing of surface and remote oceanographic data. Mr. E. L. Tilton, NASA ERL, and his successor as technical monitor, Dr. G. C. Thomann, provided guidance. Mr. J. W. Weldon, now NASA JSC, as a co-investigator did much of the operational planning and execution with Mr. K. Faller, NASA ERL, assuming the responsibilities of Mr. Weldon after the latter's departure. Mr. Faller has contributed significantly to the analysis segment of the experiment in the area of remotely sensed oceanographic data correlation to the environment.

The U.S. Air Force provided DAPS satellite data received at Keesler AFB, MS, and a U.S. Navy representative from the Environmental Prediction Research Facility, Monterey, CA, assisted in the analysis of the DAPS data. Weather data was also received through the National Environmental Satellite Service from the NOAA-2 satellite. The weather station at Eglin AFB, FL, launched a special radiosonde coincident with Skylab overpass to provide meteorological data.

Test site safety measures were coordinated with the U.S. Naval Air Station, Pensacola, FL, and the U.S. Coast Guard Headquarters at Mobile, AL. The Coast Guard Station on Santa Rosa Island, FL, provided logistics support during field operations.

The National Oceanic and Atmospheric Administration's (NOAA) National Marine Fisheries Services (NMFS) laboratories at NSTL, Pascagoula, MS, Panama City, FL, and the Southeast Fisheries Center (SEFC), Miami, FL, provided management and technical direction for the experiment. Mr. W. H. Stevenson, now at NMFS Southeast Regional Office, St. Petersburg, FL. organized and managed the experiment as the initial Principal Investigator at the NMFS Fisheries Engineering Laboratory (FEL) at NSTL. Mr. E. J. Pastula, Jr., NMFS FEL, as a co-investigator, contributed to operations and data analysis. Mr. P. C. Cook, NMFS FEL, exercised budgetary control throughout the experiment. Mr. L. Rivas, NMFS Panama City, provided technical guidance on oceanic gamefishing and also functioned as a liaison with gamefishing sportsmen and charterboat captains. Mr. E. G. Woods, NMFS FEL, planned and coordinated field operations on 4-5 August.

REFERENCES

1. Woods, E. G. and Cook, P. C., 1973: Skylab Oceanic Gamefish Project. International Gamefish Research Conference, 73 pp.

2. Savastano, K; Pastula E. Jr.; Woods G.; Faller, K.; Preliminary Results of Fisheries Investigation Associated with Skylab-3.

3. Faller, K. H., 1974: Remote Sensing of Oceanic Parameters During the Skylab/Gamefish Experiment.

4. Fox, W. W., 1971: Temporal-Spatial Relationships among Tunas and Billfishes Based on the Japanese Longline Fishery in the Atlantic Ocean 1956-1965. Sea Grant Tech. Bulletin No. 12, 77 pp.

5. Kemmerer, A. J., Benigno, J. A., Reese, G. B., and Minkler, F. C., 1973: A Summary of Selected Early Results from the ERTS-1 Menhaden Experiment, NASA CR-133152, 37 pp.

6. Wise, J. P. and Davis, C. W., 1973: Seasonal Distribution of Tunas and Billfishes in the Atlantic. NOAA Technical Report NMFS SSRF-662, 24 pp.

7. Gibbs, R. H., Jr., 1957: Preliminary Analyses of the Distribution of White Marlin, Makaira albida (Poey), in the Gulf of Mexico. Bulletin of Marine Science of the Gulf and Caribbean 7-(4) 10 pp.

8. Gulf of Mexico Its Origin, Waters, and Marine Life. Fishery Bulletin 89, Vol. 55, 1954, 601 pp.

9. De Sylva, D. P. and Davis, W. P., 1963: White Marlin, Tetrapturus albidus, in the Middle Atlantic Bight, with Observations on the Hydrography of the Fishing Grounds, Copeia, No. 1, 18 pp.

10. Daughtrey, K. R. 1973: Techniques and Procedures for Quantitative Surface Water Temperature Surveys using Airborne Sensors. Earth Resources Laboratory, Report 80, Mississippi Test Facility, 30 pp.

11. Worthington, H. T., 1973: Remote Measurement of Surface Water Temperatures in Coastal Waters, NASA Earth Resources Laboratory, Report 85, Mississippi Test Facility, 33 pp.

12. Boudreau, R. D., 1972a: A Radiation Model for Calculating Atmospheric Corrections to Remotely Sensed Infrared Measurements. NASA Earth Resources Laboratory Report 14, Mississippi Test Facility, 71 pp.

13. Boudreau, R. D., 1972b: Correcting Airborne Scanning Infrared Radiometer Measurements for Atmospheric Effects. NASA Earth Resources Laboratory Report 29, Mississippi Test Facility, 34 pp.

14. Worthington, H. T., 1974: Personal Communication.

15. Weldon, J. W., 1973: Remote Measurement of Water Color in Coastal Waters, NASA Earth Resources Laboratory, Report 83, Mississippi Test Facility, 47 pp.

16. Clark, G. L., Ewing, G., and Lorenzen, C., 1970: Spectra of Backscattered Light from the Sea Obtained from Aircraft as a Measure of Chlorophyll Concentration. Science, 67, pp 1119-1121.

17. Hovis, W. A., Forman, M. L., and Blaine, L. R., 1973: Detection of Ocean Color Changes from High Altitude, Goddard Space Flight Center Internal Technical Memorandum TMX-70559, 25 pp.

18. Jones, J. B., 1973: Determination of Chlorophyll Content of Water. Lockheed Electronics Corporation, Technical Memorandum DATM-061, Mississippi Test Facility, 7 pp.

19. Thomann, G. C., 1973: Remote Measurement of Salinity in an Estuarine Environment, Remote Sensing of Environment 2, 249 pp.

20. McClain, E. P. and Strong, A. E., 1969: On Anomalous Dark Patches In Satellite-Viewed Sunglint Areas, Monthly Weather Review, Vol 97, No. 12, pp 875-884.

21. Knudsen, M., 1962: The Determination of Chlorinity by the Knudsen Method, Reprint by G. M. Manufacturing Company, 63 p.

BIBLIOGRAPHY

Ostle, B., 1963: Statistics in Research, Second edition, The Iowa State University Press, 585 pp.

Stevenson, W. H. and Pastula, E. J., Jr., 1973: Investigation Using Data from ERTS-1 to Develop and Implement Utilization of Living Marine Resources, Final Report, Mississippi Test Facility, Bay St. Louis, Mississippi, 185 pp.

Spiegel, M. R., 1961: Schaum's Outline of Theory and Problems of Statistics, McGraw-Hill, 359 pp.

Yentsch, C. S., 1960: The Influence of Phytoplankton on the Color of Sea Water, Deep-Sea Research, Vol. 7, p. 1.

Skylab Earth Resources Data Catalog: NASA Lyndon B. Johnson Space Center, Houston, Texas.

LANDSAT DIGITAL DATA PROCESSING

A NEAR REAL-TIME APPLICATION

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ABSTRACT

An application of rapid generation of classed digital images from LANDSAT-1 was demonstrated and its feasibility evaluated by NASA in conjunction with the Environmental Protection Agency (EPA), Texas A & M University (TAMU), and the Cousteau Society. The primary purpose was to show that satellite data could be processed and transmitted to the Calypso, which was used as a research vessel, in time for use in directing it to specific locations of possible plankton upwellings, sediment, or other anomalies in the coastal water areas along the Gulf of Mexico. This was a feasibility study.

INTRODUCTION

The Calypso cruise proceeded from Key West, Florida on 8 November, 1974 to Panama City, Florida on 21 November (Figure 1). The generally east to west location of the early test sites (Figure 1, sites I-IV) provided an opportunity for sequential satellite overpasses of the test sites. The dates chosen for examination of the test sites allowed time for processing and transmitting the LANDSAT data to the ship prior to its arrival at the test site.

Of the four LANDSAT-1 images of the test areas, two were sufficiently devoid of clouds to merit further consideration: Panama City, Florida and Timbalier Bay, Louisiana (Figure 1, Test Sites III and IV). Of these two scenes, examination was particularly concentrated upon Timbalier Bay, which showed sediment-laden waters streaming from the Crowfoot Delta of the Mississippi River and dispersing in the Gulf of Mexico. In this paper, this area will be referred to as the "Mississippi Plume".

On board the Calypso for the cruise were five TAMU scientists and a representative from the Goddard Space Flight Center. NASA's first objective was to obtain ground truth data for aircraft overflights of the Coastal Zone Color Scanner (CZCS). The aircraft version of the CZCS is similar to the instrument to be flown on Nimbus-G in 1978. Both the Nimbus-G and aircraft CZCS are designed to image the sea surface in narrow spectral bands of reflectance and radiance. Secondarily, NASA desired to explore the possible applications of rapid analysis of LANDSAT data for marine coastal studies. This paper relates to the second objective. In order to proceed, NASA and EPA contracted with TAMU for the study. They, in turn, subcontracted "Calypso" as a research vessel from which to conduct oceanographic sampling.

Calypso, a converted World War II minesweeper, provided continuous sampling of sea water. Water samples collected by Calypso were analyzed for physical, chemical, and biological properties later in the TAMU laboratory.

This paper discusses the manner in which LANDSAT images were obtained, processed, and transmitted to the Calypso within three days, as well as the image interpretation and surface truth sampling programs. The feasibility of analyzing LANDSAT images in a matter of hours was demonstrated. Some usefulness of the analysis in aiding decision-making processes on a research vessel was indicated. This demonstration was made possible by a unique opportunity to use some facilities on a one-time basis for feasibility purposes only.

NEAR REAL-TIME DATA PROCESSING

The LANDSAT images used in this study were received at the GSFC tracking station. The wide-band video station tapes were processed within hours into computer compatible tapes (CCT's) by the NASA Data Processing Facility. Images on the digital CCT's were analyzed on a General Electric Image 100 interactive color TV display system. The objective of the analysis was to identify various types of water and prepare an output which could be rapidly transmitted to the Calypso.

The first cloud-free image was LANDSAT 1840-15325 (10 November, 1974). Water areas with homogeneous reflectance were identified on the color TV and used as training sites for supervised classification using all four bands (Figure 2A). In the product which was prepared for transmission, shown in Figure 2B, only one of the water classes was printed on the Gould printer-plotter. This product illustrated the boundaries between land and water, water of higher and lower reflectance, and water and clouds. The transmitted image represented about 10% of the 185 Km by 185 Km area of the original image. Individual pixels were subsampled every other line and every other column. Two types of water were identified: the highly reflective water apparently coming from the Apalachicola River into Saint George Sound and the less reflective water in the Gulf of Mexico.

The second cloud-free image was obtained on 13 November, 1974 (1843-15502). It was also processed on the Image 100 (Figure 3A). In this case the transmitted product (Figure 3B) was a full 185 Km by 185 Km LANDSAT image, subsampled every sixth column and every fifth line. Several water boundaries are visible in the monochromatic printout of the classification, with two types of water arbitrarily labeled "old silt" and "new silt". In a later processing of this image it was shown that supervised training and unsupervised level slicing of band 5 gave similar spatial distributions of water types in the Mississippi Plume area.

CLASSED IMAGE RECEPTION ON CALYPSO, AND INTERPRETATION

The monochromatic printout from the Gould Printer-Plotter was used for transmission from GSFC via slow scan facsimile over a VHF relay on the ATS-3 satellite to a synchronized facsimile recorder on board the Calypso (Figure 4). The received product showed little degradation when later compared to the original.

The classed LANDSAT image of the Panama City, Florida area was received on board the Calypso 12 November, 1974 (Figure 2B). Ground truth investigations by Calypso indicated that the highly reflective water of Saint George Sound was sediment-laden, as labeled in the image. The "air pollution plume" crossing Saint Joseph Bay was later identified as smoke from a paper mill.

The classed LANDSAT image of the Mississippi Plume area was received by Calypso on November 16, 1974 (Figure 3B). The images were on two pages and were joined together to give an overview of the Timbalier Bay and the Southwest Pass area of the Mississippi River. Later observations of the "old and new silt", made from a helicopter, suggest that the area labeled "new silt" was probably a highly concentrated area of sediments and silt and that the area labeled "old silt" was probably still part of the plume but an area of much finer siltation. From the patterns observed in Figure 3B, an initial sampling of the Mississippi Plume by Calypso was conducted on 17 November. Three stations (Figure 5, Stations V-A, V-B, V-C) were sampled, crossing the plume near the mouth of Southwest Pass. The boxed area located south of Timbalier Bay was labeled sediment, but it may have been some other material. An expanded alphanumeric printout of the boxed area was also transmitted to Calypso. Water was qualitatively broken down into various categories such as clean water, mixed water, and sediments.

The rapid analysis of the LANDSAT images enhanced the scientific program on board the Calypso. One of the major goals was to cross as many different boundary areas between as many water masses as possible. It was necessary to find these different areas in order to test the detection ability of the on-board equipment. It was shown that the more concentrated waters of the plume came directly from the Southwest Pass of the Mississippi River in a southerly direction, but turned in a more easterly direction once it came under the influence of the Gulf Stream currents. Most of these boundaries between the various plume waters were easily detected from the LANDSAT image.

INSTRUMENTATION AND PROCEDURES-CALYPSO

Oceanographic instruments and sampling procedures used on board Calypso primarily provided surface truth to aircraft overflights of the Coastal Zone Color Scanner. These instruments and sampling procedures were also instituted to study the interesting water detail shown in the classed LANDSAT image of the Mississippi Plume. Three separate studies of the plume evolved from analysis of the image. One study, on 17 November, sampled across the mouth of Southwest Pass. More detailed Calypso studies late in November and early in December sampled Stations 1 through 24 shown in Figure 5.

The following equipment, used during the entire cruise, sampled or measured the parameters of the classes of water in and around the plume: Secchi discs, bucket thermometers, precision radiation thermometer (radiometer), fluorometer, transmissometer, and scattering meter.

In addition, water samples were taken at the surface and at depths of up to 100 meters; these samples were bottled and filtered, and returned to TAMU for analysis. Zodiacs - powered rubber rafts launched from Calypso - also gathered water samples, as well as Secchi disc and bucket thermometer readings. Zodiacs sampled at one mile intervals to a distance of up to four miles at right angles to Calypso's heading.

Installed on Calypso were two satellite terminals. A direct readout meteorological satellite station received infrared and visible data from NOAA's 3 and 4. These data were used to determine weather conditions over the test areas. A VHF communications terminal provided a vital link through the ATS-3 communications satellite for coordination of experiments and for data transmission. During the data period, communications were maintained with Calypso, TAMU, and Goddard. In addition to the critical function of coordinating Calypso's position and operational readiness, LANDSAT quick-look data were transmitted via ATS-3 to Calypso for analysis and evaluation.

Since satellite overpasses preceded the water sampling by at least two days, no attempt was made to correlate the water quality parameters with LANDSAT reflectances. Sampling equipment and procedures used on this Calypso cruise should, however, provide a useful method for providing surface truth to support analysis of high resolution satellite images, if performed on a timely basis and in coordination with the satellite overpass.

CONCLUSIONS

The feasibility of near real-time monitoring of dynamic off-shore conditions from LANDSAT has been demonstrated. LANDSAT data were received at Goddard Space Flight Center. Computer Compatible Tapes produced from the original wide band video tapes were analyzed, classified on an interactive computer system, and monochromatic prints facsimiled via the ATS-3 satellite to the Calypso, located approximately 25 kilometers offshore. This process was completed in 20 hours for one site and less than three days for the other sites. Of the four LANDSAT-1 images examined, two were cloud-free. Large areas of silt and sediment were identified off the coasts of Florida and Louisiana. The monochromatic images received by Calypso are illustrative; in the future, classed images should include geographic gridding.

The rapid analysis of the LANDSAT images proved useful in helping the TAMU scientists determine the relative locations of different types of water while underway at sea, resulting in a more meaningful sampling program.

In the future, LANDSAT or some other satellite system could be used to guide research vessels to specific areas of interest. Although at present an extraordinary effort is needed on the part of NASA in order to provide this data quickly, it is hoped that future programs will include a near real-time capability for research platforms.

Cruise Track - (R/V) CALYPSO - NASA, Cruise
8th Nov. to 21st Nov., 1974

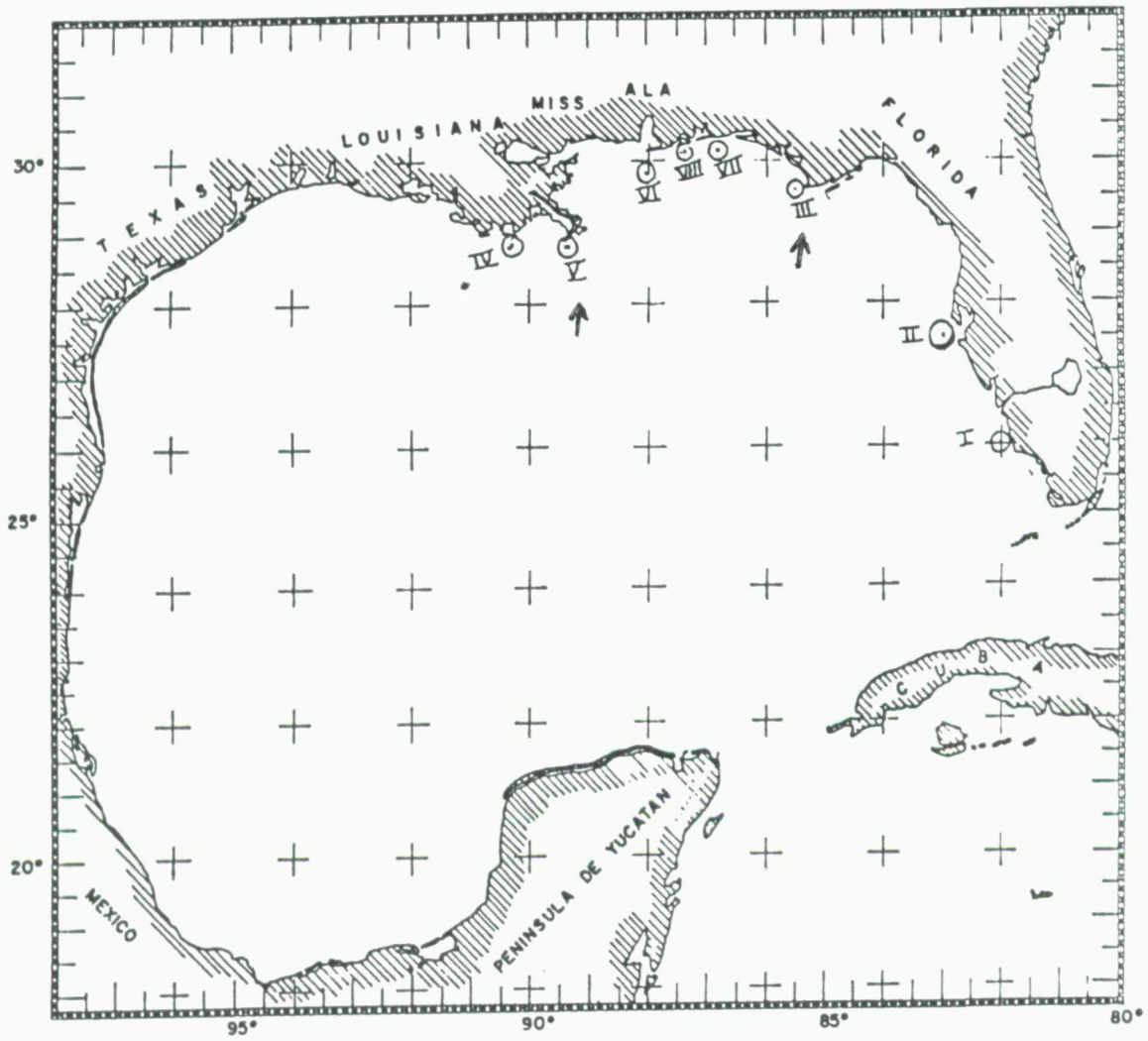


Figure 1 - Calypso Cruise Track

2067

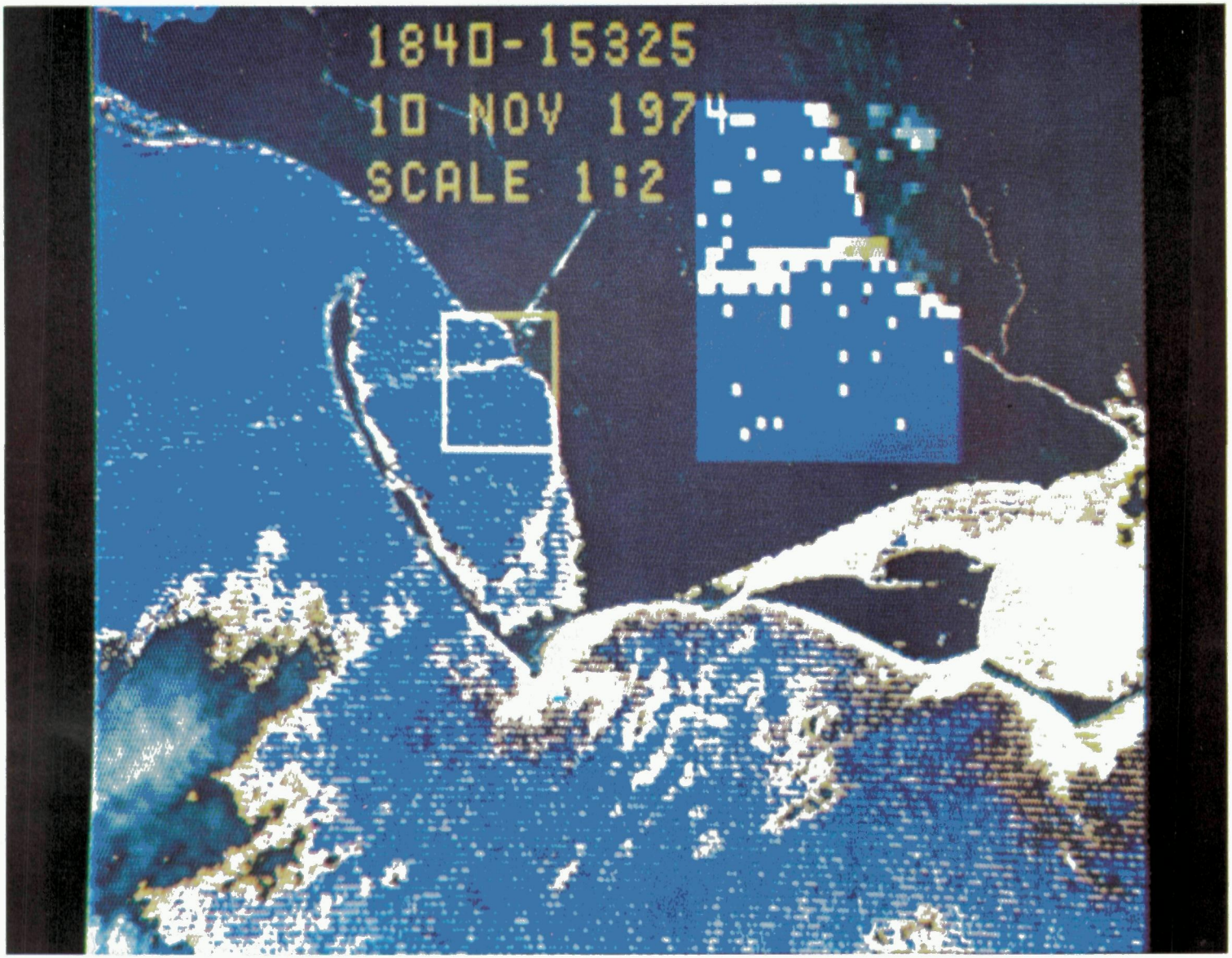


Figure 2A - Panama City Image -
Quick Look Display on an
Interactive Computer System

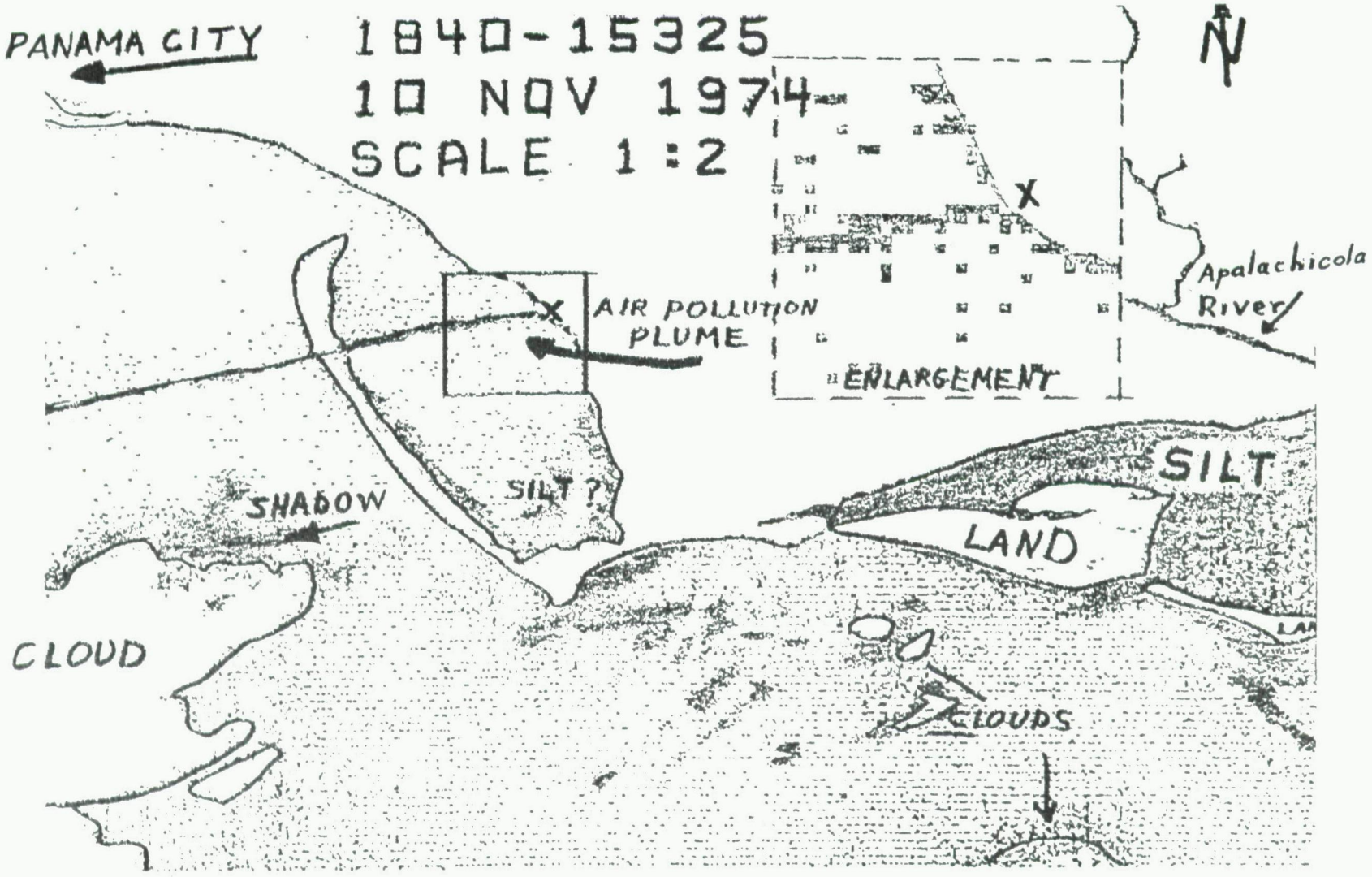


Figure 2B - Monochromatic Transmission Product - Saint Joseph Bay Part of Panama City Image with One Water Class

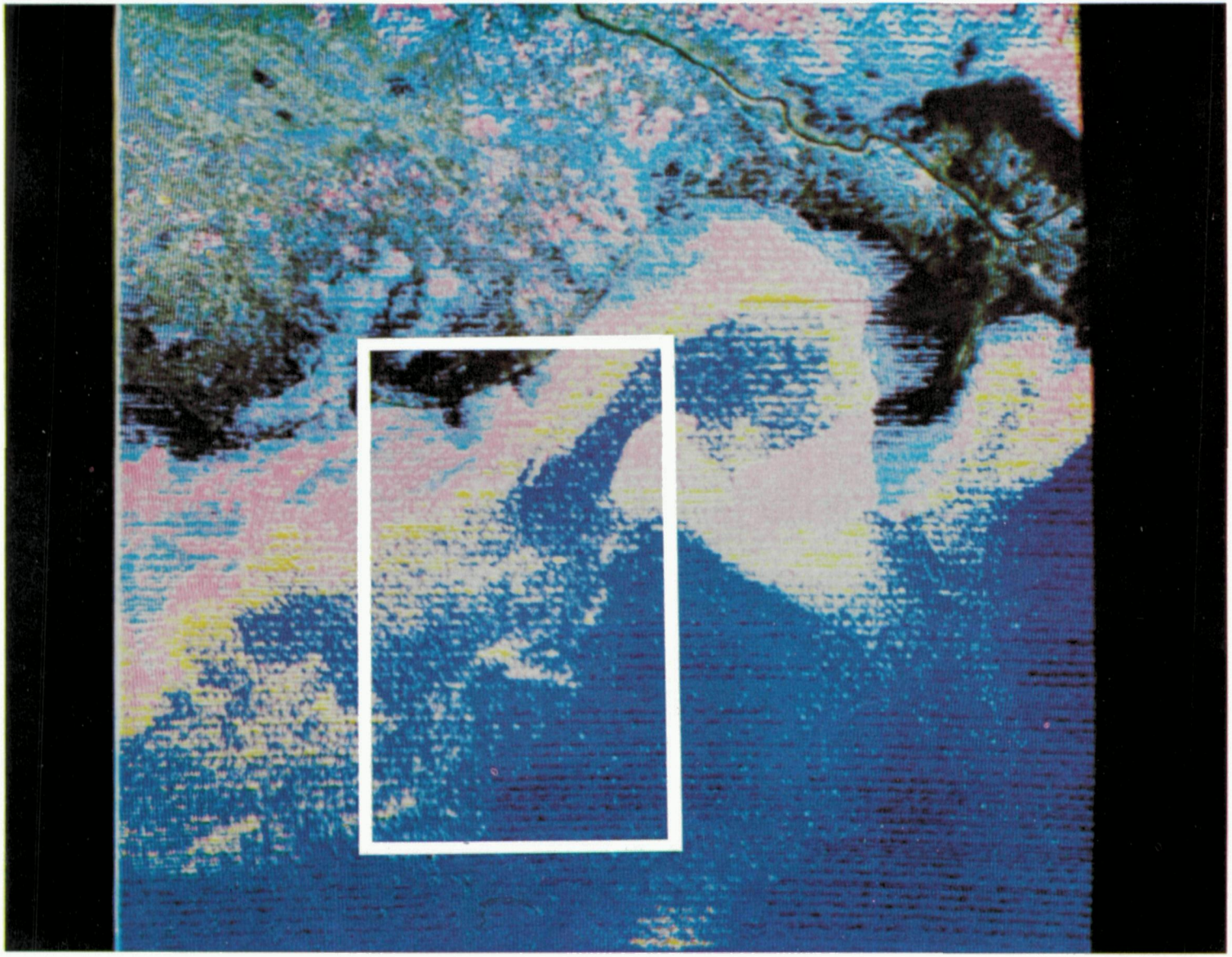


Figure 3A - Mississippi Plume Image -
Quick Look Display on an
Interactive Computer System

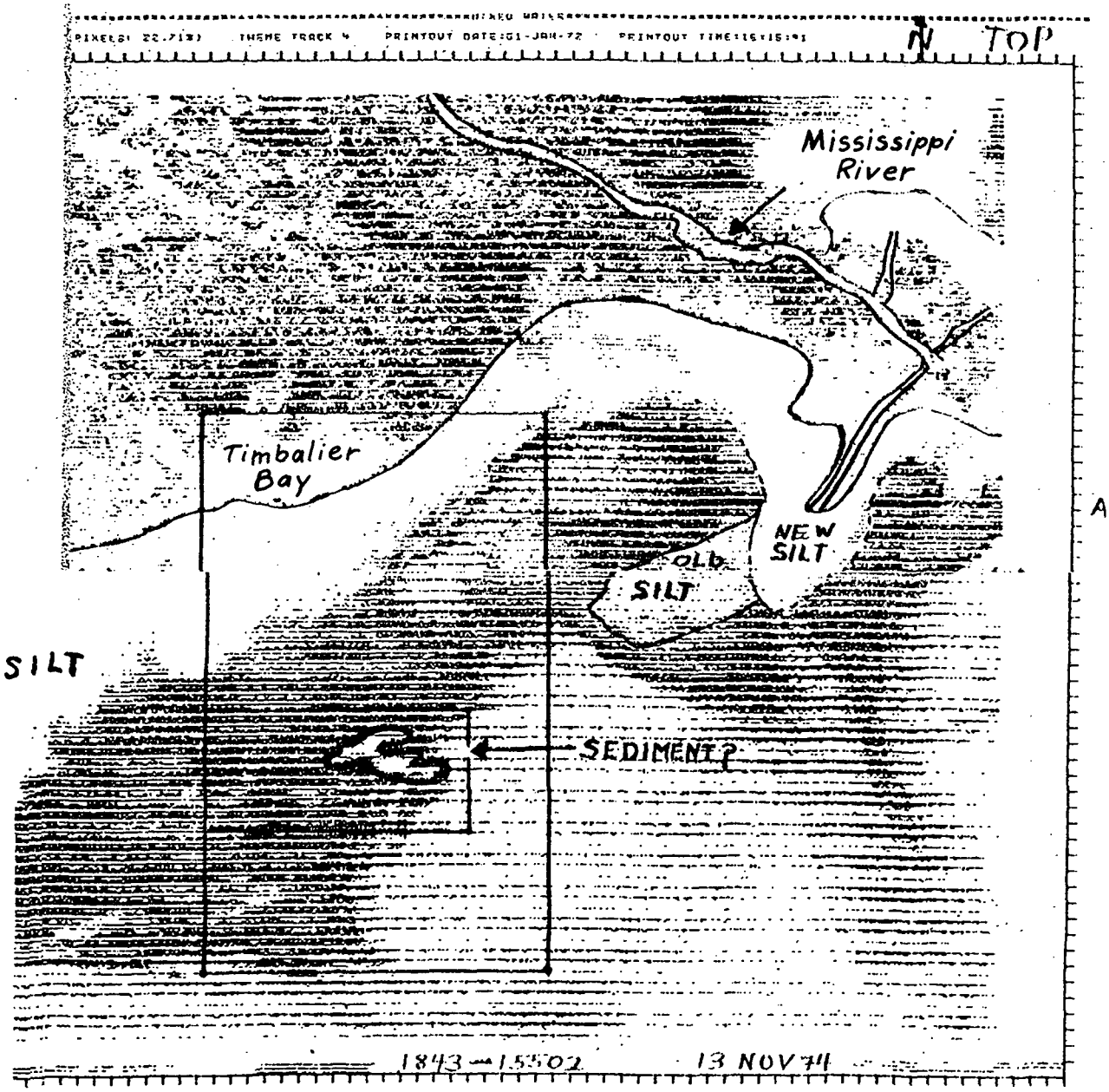


Figure 3B - Monochromatic Transmission Product - Mississippi Plume Image

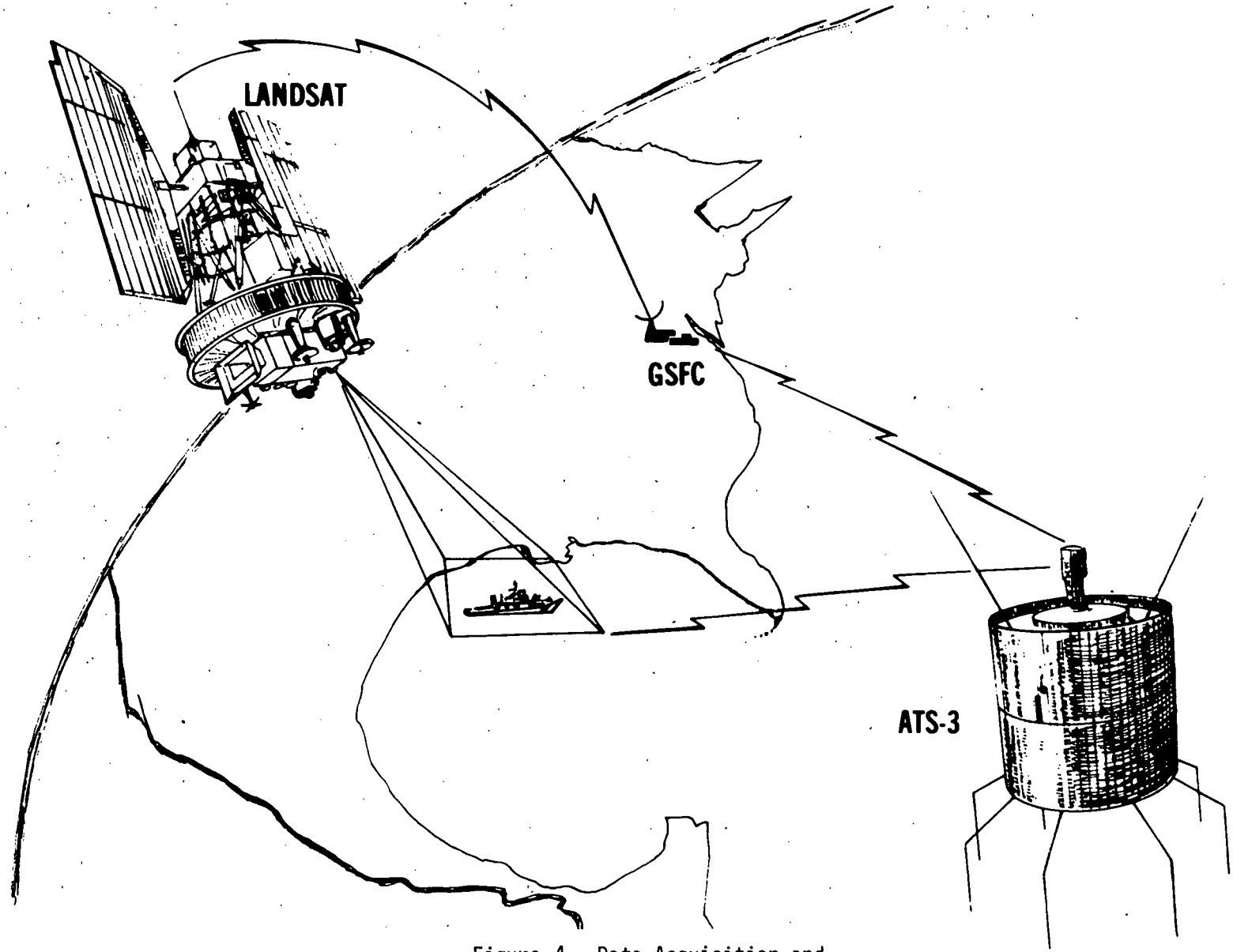


Figure 4 - Data Acquisition and Communications Network

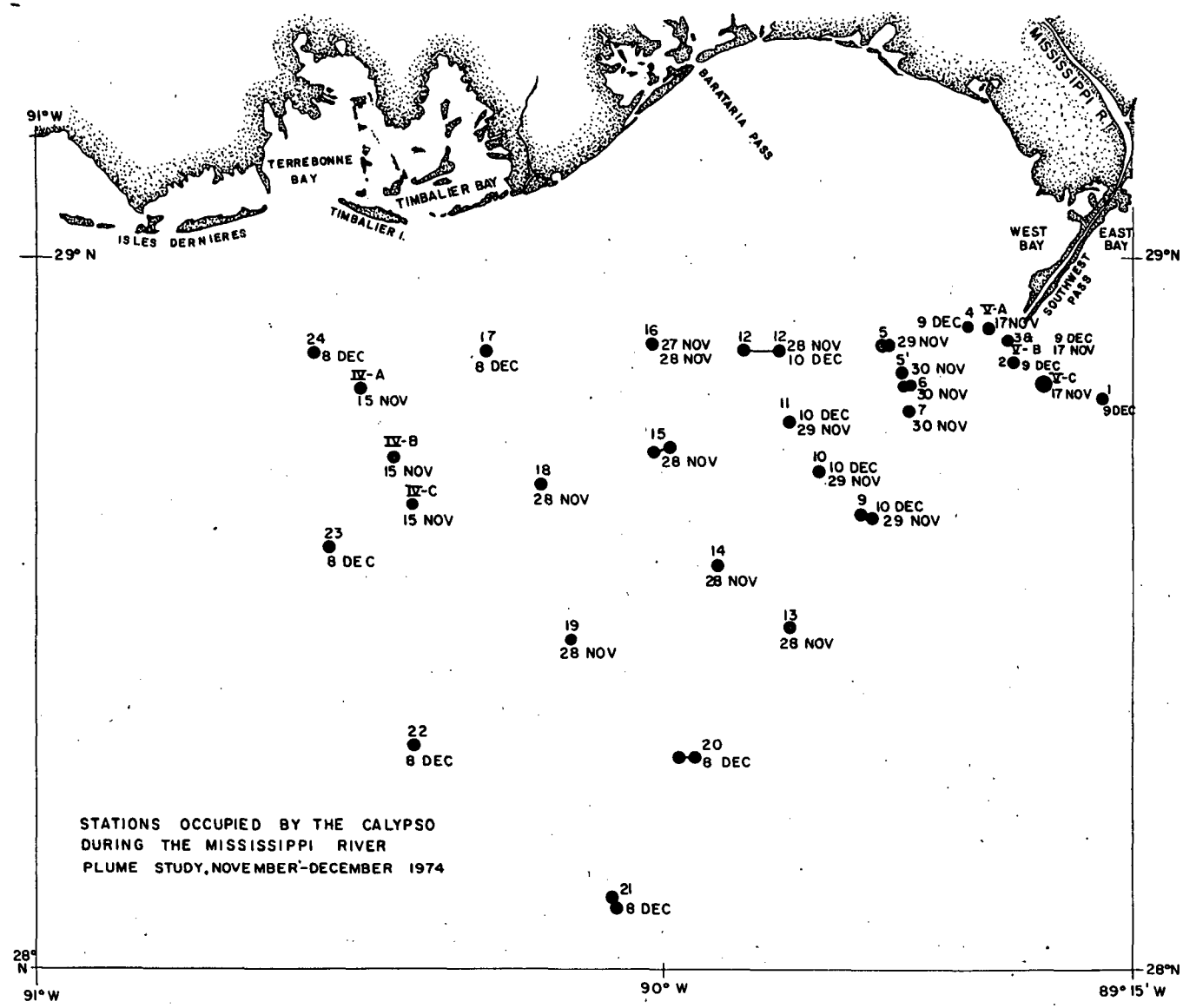


Figure 5 - Stations in Mississippi Plume

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NEARSHORE COASTAL MAPPING

M-10

By Fabian C. Polcyn, Environmental Research Institute of Michigan, Ann Arbor, Michigan, and David R. Lyzenga, Environmental Research Institute of Michigan, Ann Arbor, Michigan

ABSTRACT

Two test sites of different water quality and bottom topography have been used to test for maximum water depth penetration using the Skylab S-192 MSS for measurement of nearshore coastal bathymetry. Sites under investigation lie along the Lake Michigan coastline where littoral transport acts to erode sand bluffs and endangers developments along 1,200 miles of shore, and on the west coast of Puerto Rico where unreliable shoal location and depth information constitutes a safety hazard to navigation.

Recent collisions of oil carrying supertankers with shallow obstructions highlight the need for an up-dating of world navigation charts especially in well traveled zones.

The S-192 and S-190A and B provide data on underwater features because of water transparency in the blue/green portion of the spectrum. Depth to 20 meters have been measured with the S-192 in the Puerto Rico test site. The S-190B photography with its improved spatial resolution clearly delineates the triple sand bar topography in the Lake Michigan test site.

Several processing techniques have been employed to test for maximum depth measurement with least error. The results are useful for helping to determine an optimum spectral bandwidth for future space sensors that will increase depth measurements for different water attenuation conditions where a bottom reflection is detectable.

INTRODUCTION

The research reported here is an outgrowth and continuation of previous research projects carried out at the Environmental Research Institute of Michigan for the purpose of developing methods of extracting water-depth information from multispectral scanner data collected by aircraft and satellites [1-4]. In particular, Reference [4] describes three such methods which were successfully applied to LANDSAT-1 data from the Caribbean and Lake Michigan. The present paper describes the application of these methods to data collected by the Earth Resources Experiment Package (EREP) of the Skylab Program. In addition, this paper contains an examination of the accuracy of the results as compared with published navigational charts, and an analysis of the types and magnitudes of errors inherent in each computational method.

The application potential of this technique can be seen from the recent announcements of losses of valuable crude oil as a result of collision of supertankers in different shipping lanes around the world. In general, world navigation charts are not current due to length of time for ship collection of data and subsequent map making and the dynamic processes for shifting sand bars and creating new shoals after storms. Also charts contain notations of shoal areas that are not verified in their depth or their location is known only approximately. Space acquired data offers the potential for providing more up-to-date information for navigation purposes thereby helping to reduce losses to life and property.

METHOD DATA EXTRACTION

The data used in this research included the S-192 (multispectral scanner) and S-190 (photographic) products from all three Skylab missions. The locations and dates of the three principal data sets were:

Skylab 2, Pass 6: Southwestern Puerto Rico - June 9, 1973
Skylab 3, Pass 14: Central Lake Michigan - August 5, 1973
Skylab 4, Pass 54: Eastern Puerto Rico - November 30, 1973

Photographic products from several other passes were received, but were considered to be too cloudy to be useful for analysis. Data were received in the form of photographic transparencies (S-190A and B), magnetic tapes containing the S-192 scanner data, and screening films made from these tapes. Processing of the films included enlarging and printing by ERIM's photographic laboratory, and in some cases scanning portions of the films with a Jarrell-Ash densitometer. Magnetic tapes were first converted to ERIM format on the University of Michigan's IBM 370 computer, and subsequently processed on ERIM's IBM 7094 computer.

The end product of the digital processing is a computer generated map on which different symbols are printed corresponding to various ranges of water depth.

In this paper, a portion of the depth map for the western coast of Puerto Rico is presented. On the map, depths from 0-15 meters are indicated in 3 meter intervals by means of five symbols, a sixth symbol indicates depth from 15 to 20 meters, and a seventh symbol for depths greater than 20 meters. For a second test site in Lake Michigan, a transect perpendicular to the shoreline was made for both photographic data and S-192 CCT data. The transects are of general usefulness because of the parallel sand bar structure along the Michigan shoreline.

Three methods of extracting water depth from the multispectral data have been used in the research reported, the single channel method, the ratio method, and the optimum-decision-boundary method. The single channel method works best when uniform conditions prevails in bottom reflectivity and water absorption characteristics. The ratio method yields the smallest error due to changes in the bottom reflectivity or water quality, but is susceptible to errors due to noise or changes in the surface-reflected signals. By using two channels, quantitative measurement of depth is obtained at the expense of calculating depths to the maximum depth of the second channel which is less than the maximum depth from the best penetrating channel.

The optimum-decision-boundary technique is not limited in this way and gives the best results when two equally penetrating channels are used. The best method for any given application area depends on the data quality, channels available, and type of changes occurring in the scene.

For the single channel method, the depth z is

$$z = -\frac{1}{\alpha f} \ln \frac{L_b}{L_o}$$

where L_o = radiance at zero water depth

α = water attenuation coefficient

$f = \sec \theta + \sec \phi$

θ = scan angle (underwater)

ϕ = solar zenith angle (underwater)

L_b = bottom reflected signal

Calculation of errors with this method shows that the error due to bottom changes is independent of depth, the error due to water attenuation changes in proportion to depth, and the error due to noise or surface fluctuations increases exponentially with depth. Therefore, at large depths, the latter type of error is always predominant.

In the ratio method, the radiance is measured in two channels i and j and the water depth is calculated using the following equation:

$$z = \frac{1}{(\alpha_j - \alpha_i) f} \ln \left(\frac{L_{b_i}}{L_{o_i}} \frac{L_{o_j}}{L_{b_j}} \right)$$

where symbols are defined as before but for different spectral channels.

The advantage of this method is that in some cases, a pair of channels can be found in which the ratio of the bottom reflectivities remains constant throughout the scene, or that the changes due to absorption differences are nearly the same for all wavelengths.

In the optimum-decision-boundary method the depth is calculated by the following expression

$$z = \frac{1}{(\alpha_i^2 + \alpha_j^2) f} \left[\alpha_i \ln \frac{L_{b_i}}{L_{o_i}} + \alpha_j \ln \frac{L_{b_j}}{L_{o_j}} \right]$$

In some cases by choosing spectral channels where reflectivities are negatively correlated, the error due to changes in bottom reflectivity may be reduced.

In this method, the error due to noise or surface reflectance changes is smallest if the two attenuation coefficients are equal or nearly equal.

A total error comparison was conducted for the three methods used and the results are shown in Figure 1.

Assumed values for the comparison were

$$\rho_{bi} = .130, \ \rho_{bj} = .135, \ \Delta\rho_{bi} = .070, \ \Delta\rho_{bj} = .070$$

$$\alpha_i = .19 \ m^{-1}, \ \alpha_j = .38 \ m^{-1}, \ \Delta\alpha_i = .07 \ m^{-1}, \ \Delta\alpha_j = .06 \ m^{-1}$$

$$\frac{\Delta L_{bi}}{L_{oi}} = \frac{\Delta L_{bj}}{L_{oj}} = .05$$

The reflectance parameters were taken from measurements off the North Carolina coast. The attenuation coefficients represent a change from minimum coastal to mean coastal water [1] at .55 and .60 μm. The noise parameters are representative of raw Skylab data. This combination of parameters does not describe any actual data set processed. However, it serves to show the relative errors for each method of processing.

The smallest error at very shallow depths is obtained by the ratio method. However, the errors using this method increase very rapidly with depth. The smallest error over the largest range of depths is obtained by the optimum decision boundary method for this set of parameters. This conclusion is probably valid for most cases, unless the water surface is very smooth and the bottom variations are very large.

RESULTS

Puerto Rico - West Coast. - In September 1974 a set of data tapes was received for the June 9, 1973 pass over the western coast of Puerto Rico. This set contained all 22 channels, and the noise in some of the channels (notably band 2) was less than that on the first tape received. The new tapes also contained data from about 10 seconds earlier, thus including parts of the western coast of Puerto Rico. This was important because the data collected just before the large cloud bank over Puerto Rico contains much less low-frequency noise then the subsequent data (apparently the noise was caused by the high signal received over the clouds).

A test area was selected which included shallow water features (indicated as Escollo Negro on the Coast and Geodetic Survey Chart 901). A large part of the west coast is obscured by clouds and by a large dark plume extending outward from Mayaguez. This plume has been tentatively identified as industrial waste products (possibly including fish oil and/or molasses) from plants near Mayaguez. Within the designated area, the plume follows the deep water boundary quite closely and, therefore, does not greatly affect the depth chart.

Processing of this area began by selecting a set of points where depths were indicated on C&GS Chart 901. Data values in bands 2 and 3 at these points were then extracted from the tape. The deep water signal V_s was subtracted from each data value and the results plotted versus depth on semi-log paper (Figure 2). A linear regression analysis of this data yielded an attenuation coefficient of approximately 0.05 m^{-1} for both bands, in agreement with minimum oceanic values published in the Smithsonian Physical tables.

A digital depth chart was then produced for this area, using the optimum-decision-boundary technique with the input parameters generated by the foregoing analysis. This chart is shown in Figure 3, where the symbols correspond to the depth ranges in Table 1. The white area in the upper right-hand corner is the tip of Punta Guanajibo. A portion of Coast and Geodetic Survey Chart 901 covering the same area is reproduced as Figure 4.

Next, an accuracy check was made by comparing depth values calculated by the optimum-decision-boundary technique with values read from the C&GS Chart. Both sets of values are plotted along line 1450 in Figure 5. The root-mean-square difference between the calculated and chart values along this line is approximately 2.4 meters. Subsequently, a depth transect corresponding to line 1440 was also received from J.V.A. Trumball [5] of the U.S. Geological Survey. A portion of this transect is plotted, along with the calculated values, in Figure 6. The r.m.s. difference between the calculated and observed values along this line is approximately 3.8 meters.

The greatest difference between calculated and observed depths occurs in the narrow channel running through the Escollo Negro (at approximately point 384 in Figures 5 and 6). Neglecting the possibility that this channel has actually filled in since the depth measurements were made, the error here is probably due to slow time-response characteristics of the S-192 sensor. Calculated depths in the Canal de Guanajibo are also smaller than the measured values. This difference is perhaps due to an increased surface-reflectance signal due to nearby clouds. Other sources of error include changes in the surface-reflected signal due to sea-state conditions, and changes in water quality or bottom reflectance.

Errors due to changes in water quality or bottom reflectance can be minimized by the use of the ratio method [4], but only at the expense of increased error due to changes in the surface-reflected signal. For the present case, the minimum overall error was obtained by the use of the optimum-decision-boundary technique, chiefly because of the relatively poor data quality in the red band (band 5) which is used in the ratio method.

Experience with low-altitude aircraft data [1-3] has indicated that depth accuracies on the order of 10-20% can be obtained using the ratio method. For a test site on Lake Michigan [3], the r.m.s. difference between the actual depth and the calculated depth using

wavelength bands of .57-.62 μm and .62-.69 μm was approximately 2.4 feet, out of a maximum depth of 25 feet. These results were obtained with the M-7 aircraft scanner [6], which has a noise-equivalent radiance of approximately 0.12 mw cm^{-2} μm^{-1} in these bands. The data was also smoothed to further reduce noise.

Lake Michigan Shoreline. - Data tapes from Skylab-3 pass 14 over Lake Michigan were received at ERIM in October 1974. Data was taken over the eastern shore of Lake Michigan during this pass at 15:01:30 GMT on 5 August 1973. Skies were clear over the Michigan shoreline and the solar zenith angle was approximately 45°.

Very little shallow water is visible in the scene because of the rapid drop-off in water depth along the shoreline. A Jarrell Ash scanning densitometer was used on an enlargement of S-190B photographic transparency to confirm distances measured by the S-192 data.

The densitometer scan shows three peaks at locations corresponding very closely to the peaks in the S-192 data. Assuming these are sandbars, the water depth can be calculated at each sandbar if the water attenuation coefficient is known. Unfortunately, no ground truth data was collected at this time of the overflight. However, an estimate can be made by using the attenuation coefficient $\alpha = .055$ ft^{-1} reported by Brown et al. [3] for Lake Michigan water at the wavelengths corresponding to band 3. The equation relating signal to depth is:

$$V = V_s + V_o e^{-\alpha f z}$$

where V = signal at depth z in band 3

V_s = signal over deep water ($z = \infty$)

V_o = bottom-reflected signal at shoreline ($z = 0$)

α = water attenuation coefficient

$f = \sec\theta + \sec\phi$

θ = scan angle (underwater)

ϕ = solar zenith angle (underwater)

Using the observed values $V_s = 55$, $V_o = 15$, and $f = 2.42$, the depths calculated for each sandbar are 13.4 ft, 10.0 ft, and 8.3 ft, respectively.

No direct depth measurements were made in this area, but Lake Survey Chart 77 shows two sandbars south of Pentwater at distances of about 210 and 360 meters from shore. The depths are indicated as about 6 and 10 feet, respectively, in fair agreement with the calculated depths. No third sandbar is shown on the Lake Survey Chart, but its existence is possible since they are known to form and disappear quite rapidly due to wave action.

CONCLUSIONS

The examples discussed in this paper indicate that shallow water features can be located rapidly using space-acquired imagery. Photographs provide greater spatial resolution but multispectral scanner data is needed to distinguish underwater features from surface phenomena and to provide quantitative estimates of water depth.

Significant improvement in depth penetration and spatial resolution over LANDSAT-1 data has been noted in Skylab scanner and photographic data. Skylab sensors have better band location, bandwidth, and gain characteristics than LANDSAT-1. However, the Skylab scanner has been plagued with noise and poor response characteristics, which have in some cases rendered the data less useful than LANDSAT-1 data. Attempts to use ratio depth processing have been less successful with Skylab than with LANDSAT data because of the noise in band 5. Methods of reducing noise by smoothing are less successful because of the conical scan configuration. However, the striping problem in LANDSAT due to differences in calibration of the six sensors is not present in Skylab.

Coordination of data products and determination of orbital and sensor parameters has been more difficult with Skylab than with LANDSAT data. Despite these problems, however, Skylab has generated a large amount of useful data which could be exploited by the techniques reported here, to contribute to the general store of hydrographic information or solve specific problems where an up-to-date knowledge of shallow water bottom topography over a large area is needed.

REFERENCES

1. F. C. Polcyn and R. A. Rollin, "Remote Sensing Techniques for the Location and Measurement of Shallow-Water Features," Report No. 8973-10-P, Willow Run Laboratories, January 1969.

2. F. C. Polcyn, W. L. Brown, and I. J. Sattinger, "The Measurement of Water Depth by Remote Sensing Techniques," Report No. 8973-26-F, Willow Run Laboratories, October 1970.

3. W. L. Brown, F. C. Polcyn, A. N. Sellman, and S. R. Stewart, "Water Depth Measurement by Wave Refraction and Multispectral Techniques," Report No. 31650-31-T, Willow Run Laboratories, August 1971.

4. F. C. Polcyn and D. R. Lyzenga, "Remote Bathymetry and Shoal Detection with ERTS", Report No. 193300-51-F, Environmental Research Institute of Michigan, April 1975.

5. J. V. A. Trumball, personal communication, April 11, 1975.

6. P. G. Hasell, et al., "Michigan Experimental Multispectral Mapping System - A Description of the M7 Airborne Sensors and its Performance", Report No. 190900-10-T, Environmental Research Institute of Michigan, January 1974.

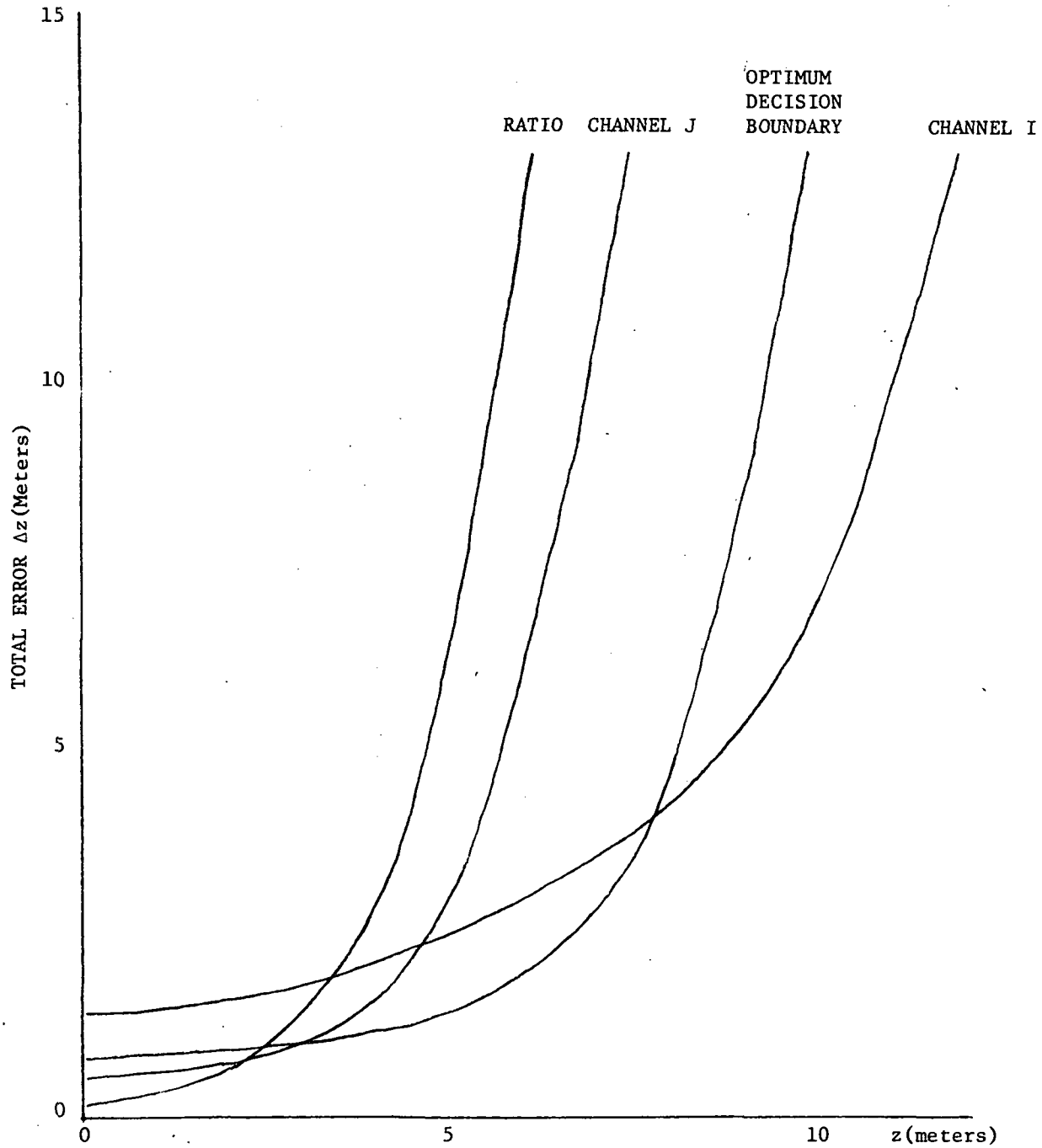


FIGURE 1. COMPARISON OF TOTAL ERROR

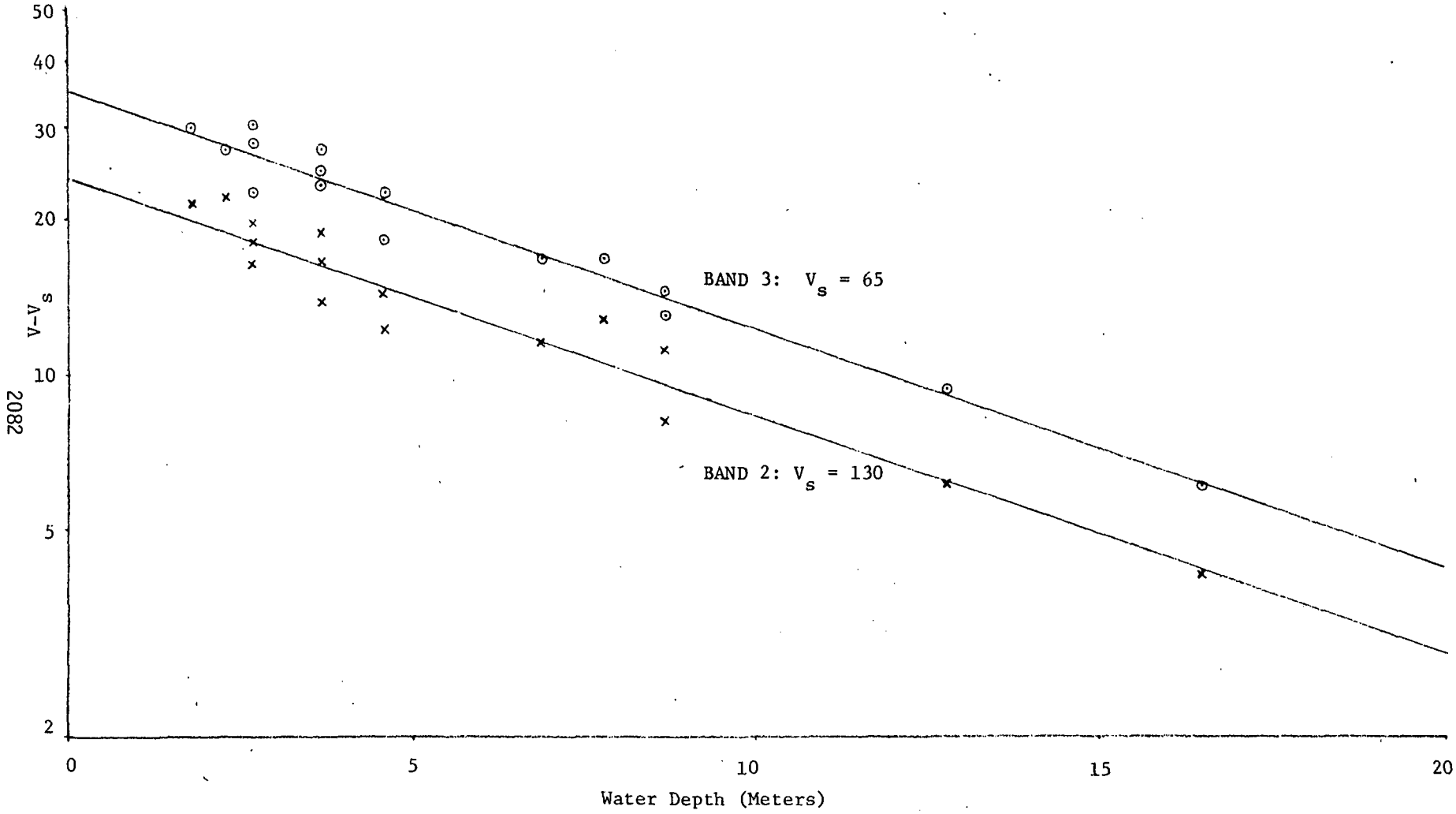


FIGURE 2. BAND 2 AND 3 SIGNALS VERSUS DEPTH, ESCOLLO NEGRO AREA.

TABLE I

METERS	SYMBOL
20-INF	⊠ = Blue
15-20	X = Blue
12-15	* = Blue
9-12	+ = Blue
6-9	* = Red
3-6	X = Red
0-3	⊠ = Red
LAND	

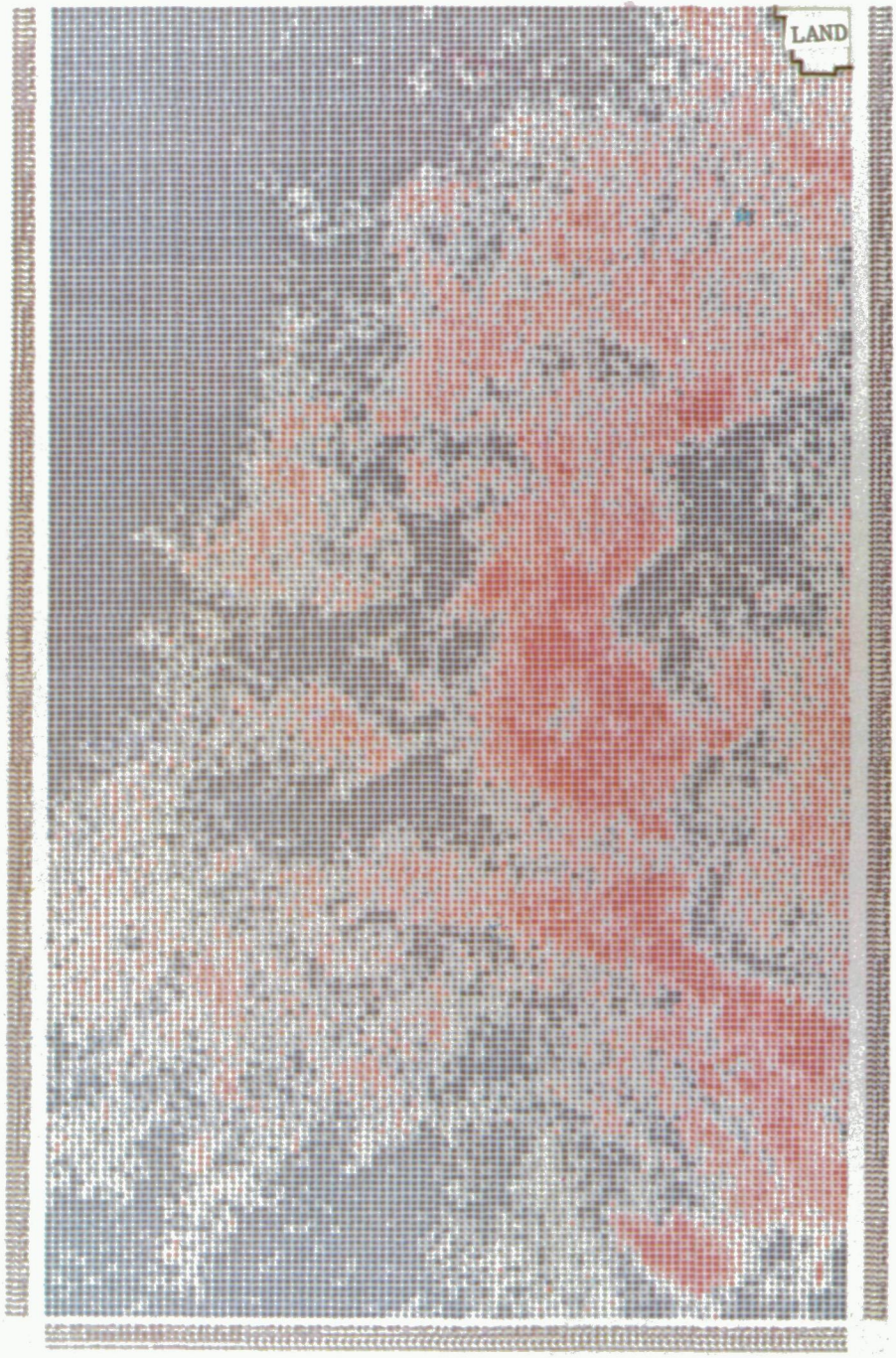


FIGURE 3. DIGITAL DEPTH CHART OF ESCOLLO NEGRO AREA

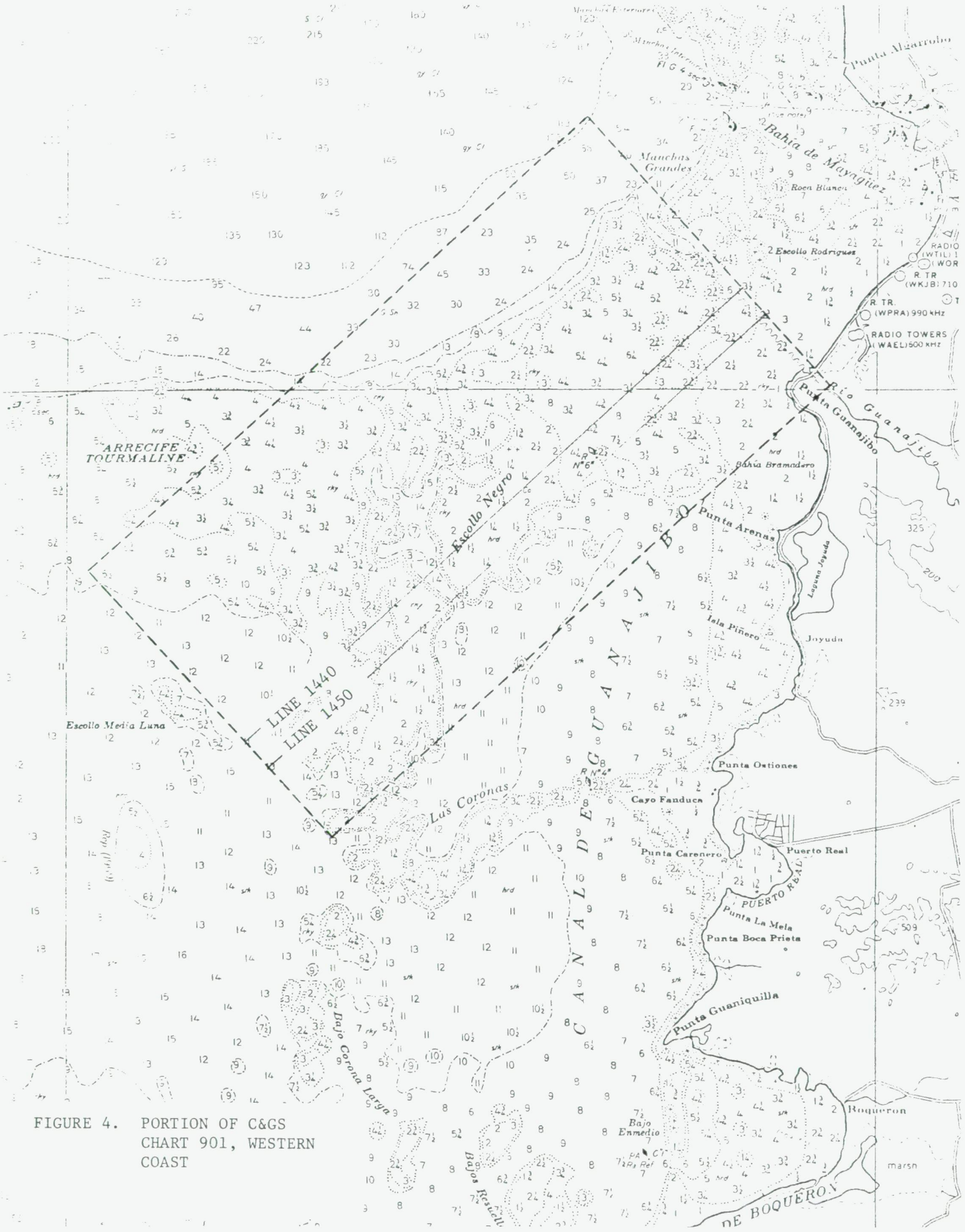


FIGURE 4. PORTION OF C&GS CHART 901, WESTERN COAST

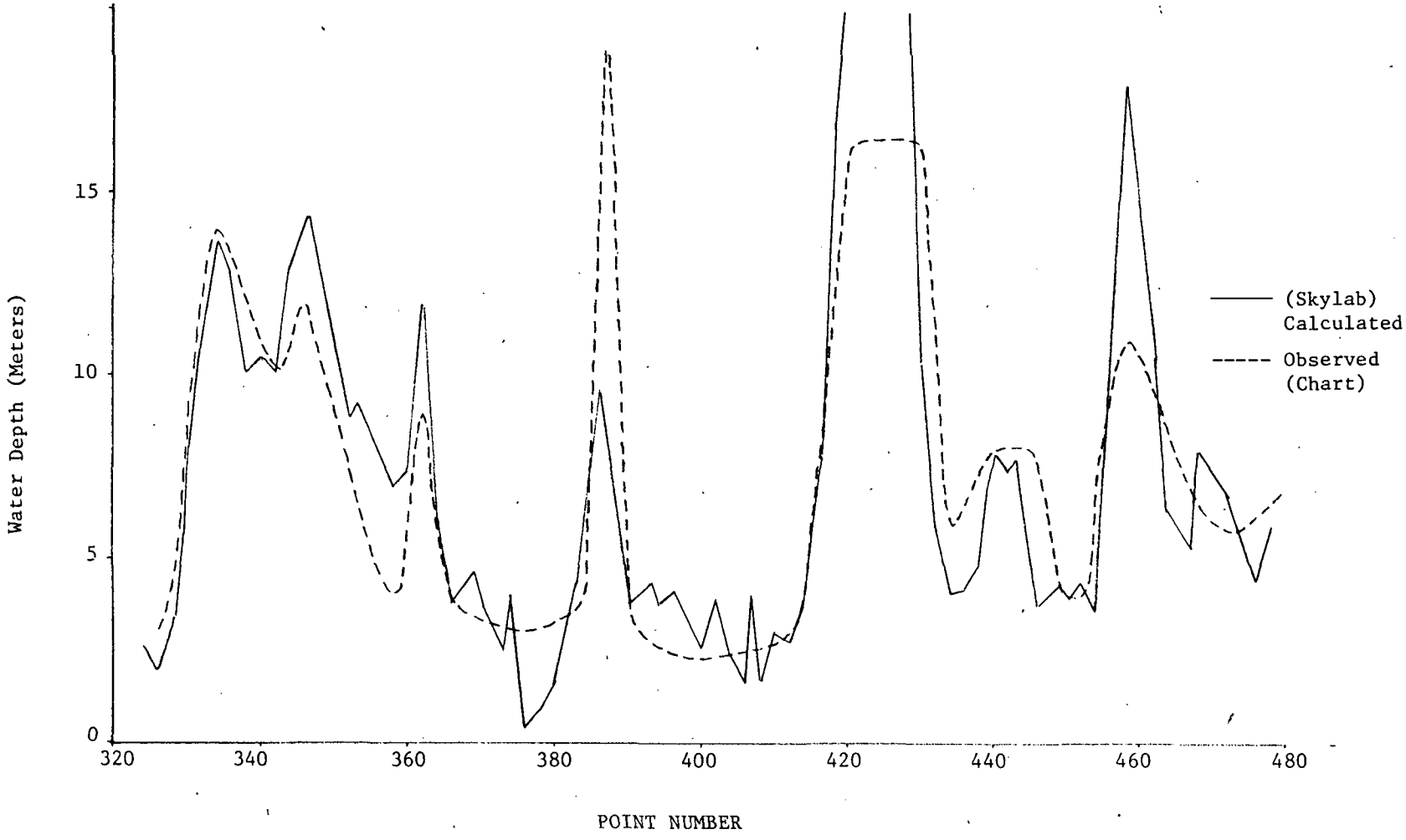


FIGURE 5. CALCULATED AND CHART DEPTHS ALONG LINE 1450

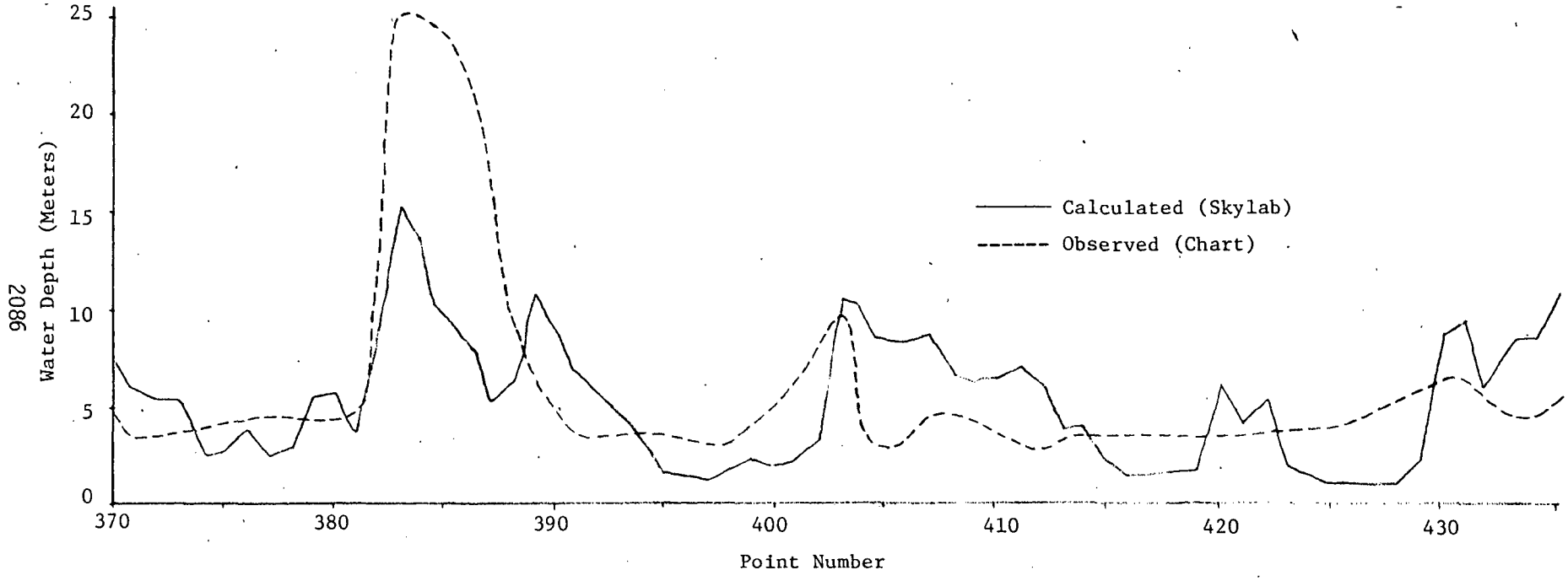


FIGURE 6. CALCULATED AND OBSERVED DEPTHS ALONG LINE 1440.

QUANTITATIVE SUSPENDED SEDIMENT MAPPING USING AIRCRAFT REMOTELY SENSED MULTISPECTRAL DATA

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ABSTRACT

Suspended sediment is an important environmental parameter for monitoring water quality, water movement, and land use. Quantitative suspended sediment determinations have been made from analysis of aircraft remotely sensed multispectral digital data. A statistical analysis and derived regression equation were used to determine and plot quantitative suspended sediment concentration contours in the tidal James River, Virginia, on May 28, 1974. From the analysis, a single band, Band 8 (0.70-0.74 microns), was adequate for determining suspended sediment concentrations. A correlation coefficient of 0.89 was obtained with a mean inaccuracy of 23.5 percent for suspended sediment concentrations up to about 50 mg/ℓ. Other water quality parameters - secchi disc depth and chlorophyll - also had high correlations with the remotely sensed data. Particle size distributions had only a fair correlation with the remotely sensed data.

INTRODUCTION

Suspended sediment is an important environmental parameter for monitoring water quality, water movement, and land use in river water sheds and filling rates in reservoirs. Uncontrolled sediment runoff reduces the depth of the photic zone and therefore the volume of water in which photosynthesis (oxygen production) can take place. Suspended sediment has also been recognized as a natural tracer that may be used to measure flow and distributions in a water body, thereby providing information on pollutant concentrations and dispersions. In addition, high sediment loads may be indicative of harmful erosion of nearby land areas and/or high filling rates in reservoir systems.

Williamson and Grabau (ref. 1) and Klemas, et al. (ref. 2) analyzed LANDSAT multispectral scanner data and determined suspended sediment concentration categories in the areas of water analyzed. A typical water category had sediment concentrations from 15 to 25 mg/ℓ. Johnson (ref. 3) applied a continuous function analysis to develop a regression equation to determine sediment concentrations for each pixel. By this latter procedure it was possible to determine and plot quantitative suspended sediment concentration contours as shown in figure 1, which is taken from reference 3.

It is the purpose of this investigation to apply the methodology of reference 3 to aircraft multispectral scanner data to quantitatively determine suspended sediment concentrations in a turbid tidal river system. In addition, other water quality parameters such as chlorophyll, secchi disc depth and particles will be investigated for correlations among themselves and with the digital multispectral scanner data.

EXPERIMENTAL METHOD

Remotely sensed data were collected in conjunction with ground truth measurements over the Norfolk and James River, Virginia, areas on May 28, 1974. Remotely sensed data were collected from about 1015 to 1135 hours e.d.t. by a Bendix Modular Multispectral Scanner (M2S) from a flight altitude of 8000 feet (2.4 km). Ground truth measurements were made from seven boats at three sites; Norfolk, Hopewell, and Hog Island. Three boats were located at each of the first two sites, Norfolk and Hopewell, and one boat was used at Hog Island. In situ measurements were made and water samples taken for subsequent laboratory

determinations at 20-minute intervals from about 0935 to 1235 hours e.d.t. A wide range of water parameters were measured. This investigation will consider suspended sediment, secchi disc depth, chlorophyll, and particle size distributions.

Remotely sensed data were collected by an 11-band (10 bands in the visible and near IR and one thermal band) multispectral scanner (Bendix M2S). Bandwidths and frequencies are listed in table I, along with spatial coverage information at the flight altitude. Pixel size and resolution are about 25 feet (7 m). Multispectral scanner imagery in Band 5 (0.58-0.62μ) over the test areas is shown in figure 2.

Digital data in the visible and near IR frequencies were analyzed using statistical regression techniques to develop an equation for quantitatively determining suspended sediment concentrations. In the analysis, suspended sediment concentration (mg/ℓ) is the dependent variable and the 10 bands of remotely sensed data (mw/cm^2-ster) are the independent variables. Correlation among the M2S bands and with suspended sediment is generally high except for widely separated bands, as shown in the linear correlation matrix, table II. Individual band correlations with suspended sediment are high for Bands 4 through 9 which cover a frequency range from 0.54 to 0.86μ, with Band 8 (0.70-0.74μ) the highest with a correlation coefficient of 0.89.

To develop a better assessment of the data set, a stepwise regression analysis (SRA) technique was applied to the data. In an SRA the program will determine the one independent variable (radiance) that provides the best statistical correlation with the dependent variable (suspended sediment concentration), then in successive steps determines a second variable to be added that improves the multiple correlation and so on until all of the independent variables have been included in the correlation. The first step provides information on the best single band. Additional steps provide a measure of the improvement as successive information (bands) are added.

Results of the analysis are shown below.

Step	Independent variable added	Regression variables	Std. error of estimate mg/ℓ	Regression correlation coefficient
1	R8	R8	4.76	0.888
2	R1	R8, R1	4.68	.896
3	R6	R8, R1, R6	4.58	.903
.	.	.	.	.
.	.	.	.	.
.	.	.	.	.
10	R10	All	4.31	.927

where RN is radiance (mw/cm^2-ster) from the M2S in Band N (i.e., R8 is the radiance in Band 8). Standard error of estimate is the statistical standard deviation in mg/ℓ. Regression correlation coefficient is a measure of the relative responses of the variables with a maximum value of unity.

To test the assumed linear regression equation, residuals (deviations from the fitted regression line) were plotted as a function of sediment concentration, figure 3. Since the variation of residuals occurred approximately randomly the linear equation appears to be adequate. Johnson (ref. 3) and McCauley and Yarger (ref. 4) have previously indicated linear response of suspended sediment concentrations with radiance in this range of values.

A one-parameter (Band 8) regression equation was used for the determination of suspended sediment since the addition of other variables (M2S bands) does not make a significant improvement (based on reduction in sum of squares for 95-percent confidence level, e.g., p. 455, ref. 5) for this particular data set. The resultant equation for a single band regression is

Suspended sediment concentration (mg/ℓ) = -88.80 + 600.00R8

Estimated mean inaccuracy using the above equation is about 23.5 percent (standard error of estimate 4.76 mg/ℓ and an average sediment concentration of 20.22 mg/ℓ). Sediment concentrations range up to about 50 mg/ℓ. Suspended sediment concentrations, Band 8 response, and the fitted regression line are shown in figure 4.

Quantitative values of suspended sediment concentrations may be used to determine and plot contours of equal concentrations in the study area. Contours in the upper James River near Hopewell are shown in figure 5. Comparison with the same area in figure 2 indicates the same suspended sediment characteristics; however, the contour plots provide quantitative values of suspended sediment concentrations, rather than relative (or qualitative) measures.

In addition to suspended sediment concentrations, ground truth measurements included other water quality parameters: chlorophyll a, secchi disc, and particle size distributions. The latter were determined from the Langley computerized particulate counter (Millipore πMC). Correlations among these parameters are shown in a correlation matrix (table III). Poor correlations were obtained for very small particles (less than 1 micron). Relatively good correlations with suspended sediment were obtained for small to medium size (1.0 to 4.0μ) and for total particles. This correlation is not as good as might be expected under the good conditions for sediment resuspension - shallow water areas on each side of the channel, fresh water outflow combined with ebb tide over the data collection period, and a 15- to 20-knot wind blowing down the river. A high correlation (negative sign indicates inverse relationship) was obtained between secchi disc depth and suspended sediment concentration as expected. The high correlation between chlorophyll a and suspended sediment concentrations, in addition to the essentially parallel response to suspended sediment concentrations in the particle distributions, indicates that this may be a parallel correlation with particles; however, the analysis technique provides separation of chlorophyll in this particular set of data. Day-to-day correlations of chlorophyll that did not show a high correlation as grouped data have been previously observed by Bowker and Witte (ref. 6) in their analysis of LANDSAT data from the Chesapeake Bay.

Further analysis of the chlorophyll a data was obtained by taking chlorophyll as the dependent variable and multispectral responses as the independent variables, as was done for suspended sediment. Again, the stepwise regression approach was followed. Results of the analysis were

Step	Independent variable added	Regression variables	Std. error of estimate, mg/M^3	Regression correlation coefficient
1	R8	R8	2.64	0.89
2	R2	R8,R2	1.88	.95
3	R4	R8,R2,R4	1.70	.96
4	R9	R8,R2,R4,R9	1.62	.96
5	R5	R8,R2,R4,R9,R5	1.60	.97
		0		
		0		
		0		
10	R4	All	1.56	.97

where the statistical parameters are the same as previously defined.

The mean inaccuracy of chlorophyll determinations from the regression equation (for a mean chlorophyll concentration of 6.9 mg/M^3) varies from about 36 percent for a one-parameter equation to about 22 percent for a regression equation of three variables. It is

interesting that the two most significant variables, R8 and R2, are essentially the same as for the sediment correlation (R8 and R1 for sediment), thus, it appears, as noted above, that the correlation of chlorophyll with multispectral response is related to the particle response.

CONCLUDING REMARKS

Multispectral scanner digital data have been analyzed to develop a regression equation for determining suspended sediment concentrations. A linear equation using one band, Band 8 (0.70-0.74μ), appears to be adequate for in-scene analysis for this particular data set although addition of other bands marginally improves the correlation coefficient and in most cases mean inaccuracy is less. Mean error associated with application of the regression equation to determining suspended sediment concentration contours is 23.5 percent for sediment concentrations up to about 50 mg/ℓ. Variations of equal or greater magnitude might be expected from measurement and spatial inaccuracies due to ground truth measurement and/or spectral inaccuracies due to particle composition and size distributions.

Analysis of additional water quality parameters - chlorophyll a, secchi disc depth, and particle size distributions - indicates the multispectral scanner data are "suspended sediment dominated," thus it is difficult to analyze for other materials. A high correlation was obtained between chlorophyll a and multispectral scanner data; this appears to be due to particles that contain chlorophyll, rather than chlorophyll per se and the specific relationship is probably limited to this set of data.

Additional remotely sensed data in conjunction with ground truth from a number of environmentally different areas will be required to further define the accuracy of and conditions under which regression equations for quantitative analysis of digital multispectral data may be applied.

REFERENCES

1. Williamson, A. N., and W. E. Grabau. Sediment Concentration Mapping in Tidal Estuaries. Third Earth Resources Technology Satellite-1 Symposium, Washington, D.C., December 10-14, 1973.

2. Klemas, V., M. Otley, W. Philpot, C. Wethe, and R. Rogers. Correlation of Coastal Water Turbidity and Circulation with ERTS-1 and Skylab Imagery. Presented at the Ninth International Symposium on Remote Sensing of Environment, Univ. of Michigan, Ann Arbor, Michigan, April 15-19, 1974.

3. Johnson, Robert W. Quantitative Sediment Mapping from Remotely Sensed Multispectral data. Presented at the Fourth Annual Remote Sensing of Earth Resources Conference, March 24-26, 1975, Tullahoma, Tennessee.

4. McCauley, James, and Harold Yarger. Kansas Water Quality Using ERTS-1. Presented at the Fourth Annual Remote Sensing of Earth Resources Conference, March 24-26, 1975, Tullahoma, Tennessee.

5. Snedecor, George W., and William G. Cochran. Statistical Methods. Sixth Edition, The Iowa State University Press, Ames, Iowa, 1967.

6. Bowker, David E., and William Witte. Evaluation of ERTS MSS Digital Data for Monitoring Water in the Lower Chesapeake Bay Area. Presented at the Fourth Annual Remote Sensing of Earth Resources Conference, March 24-26, 1975, Tullahoma, Tennessee.

Table I. Multispectral Scanner (M2S) Bandwidths and Frequencies, and Spatial Coverage at 8000-Foot (2.4 km) Altitude.

MAY 28, 1974

SPECTRAL

RANGE	380 - 1060 nm + THERMAL	
BANDS	BAND	RANGE
	1	380 - 440 nm
	2	440 - 490 nm
	3	495 - 535 nm
	4	540 - 580 nm
	5	580 - 620 nm
	6	620 - 660 nm
	7	660 - 700 nm
	8	700 - 740 nm
	9	760 - 860 nm
	10	970 - 1060 nm
	THERMAL	8000 - 13 000 nm

SPATIAL

FIELD OF VIEW	
WIDTH, M	6800
LENGTH, M	CONTINUOUS
RESOLUTION, M	7

Table II. Linear Correlation Matrix of Suspended Sediment (mg/ℓ) and Multispectral Scanner Response (mw/cm^2-ster).

		M2S BANDS									
	SEDIMENT	1	2	3	4	5	6	7	8	9	10
SEDIMENT	1.000	0.464	0.546	0.503	0.788	0.860	0.878	0.849	0.888	0.857	0.639
1		1.000	.889	.855	.786	.691	.659	.664	.632	.630	.558
2			1.000	.961	.906	.822	.782	.811	.707	.712	.654
3				1.000	.877	.778	.728	.779	.654	.679	.600
4					1.000	.975	.959	.966	.908	.876	.704
5						1.000	.987	.989	.954	.924	.747
6							1.000	.988	.968	.926	.737
7								1.000	.956	.933	.753
8									1.000	.946	.720
9										1.000	.840
10											1.000

Table III. Linear Correlation Matrix of In Situ Water Quality Parameters on May 28, 1974, in James River, Virginia.

	SEDI-MENT	CHLOR *a*	SECCHI DISC	PARTICLES 0-0.5μ	0.5-1μ	1-2μ	2-4μ	4-8μ	8-16μ	TOTAL
SUSPENDED SEDIMENT	1.000	0.824	-0.879	-0.306	-0.407	0.635	0.461	0.413	0.138	0.543
CHLOR *a*		1.000	-.810	-.285	-.355	.668	.516	.447	.033	.565
SECCHI DISC			1.000	.315	.435	-.747	-.502	-.426	-.071	-.589
PARTICLES 0-0.5μ				1.000	.542	-.067	-.109	-.091	-.094	-.105
PARTICLES 0.5-1μ					1.000	-.130	-.031	-.054	-.103	-.077
PARTICLES 1-2μ						1.000	.854	.722	.023	.896
PARTICLES 2-4μ							1.000	.929	.051	.961
PARTICLES 4-8μ								1.000	.042	.889
PARTICLES 8-16μ									1.000	.271
TOTAL PARTICLES										1.000

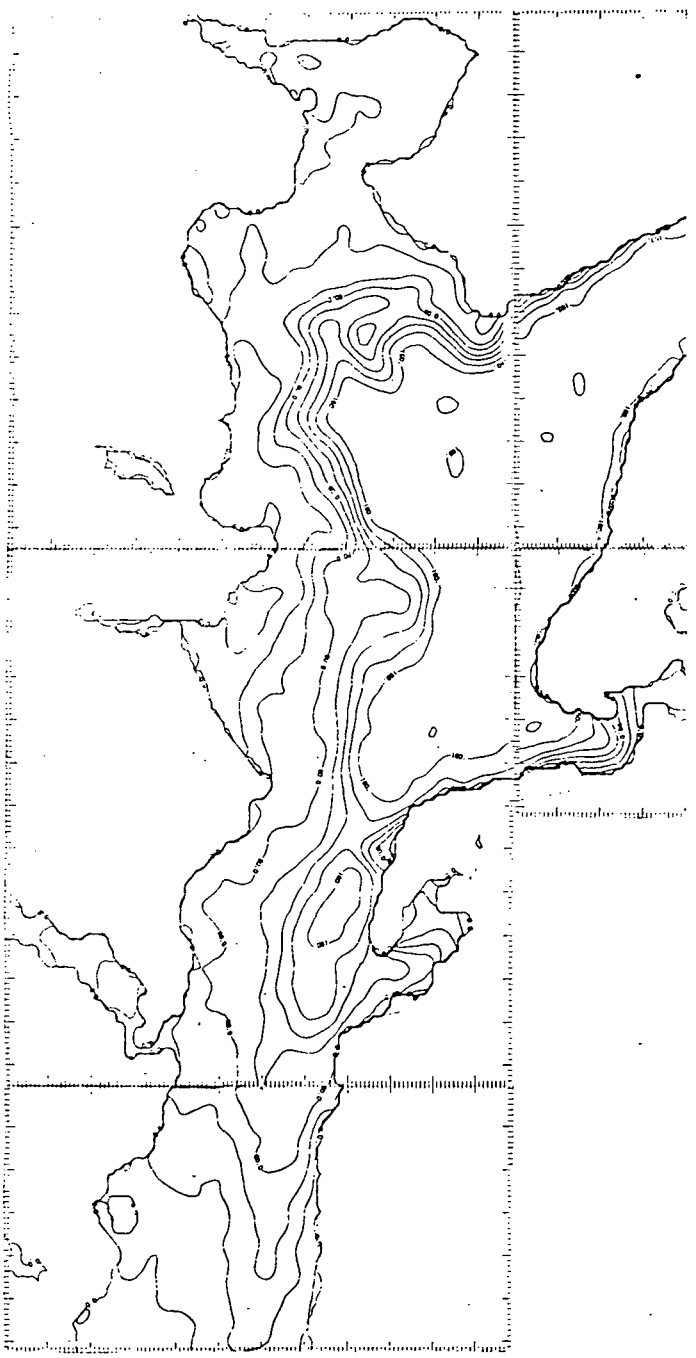
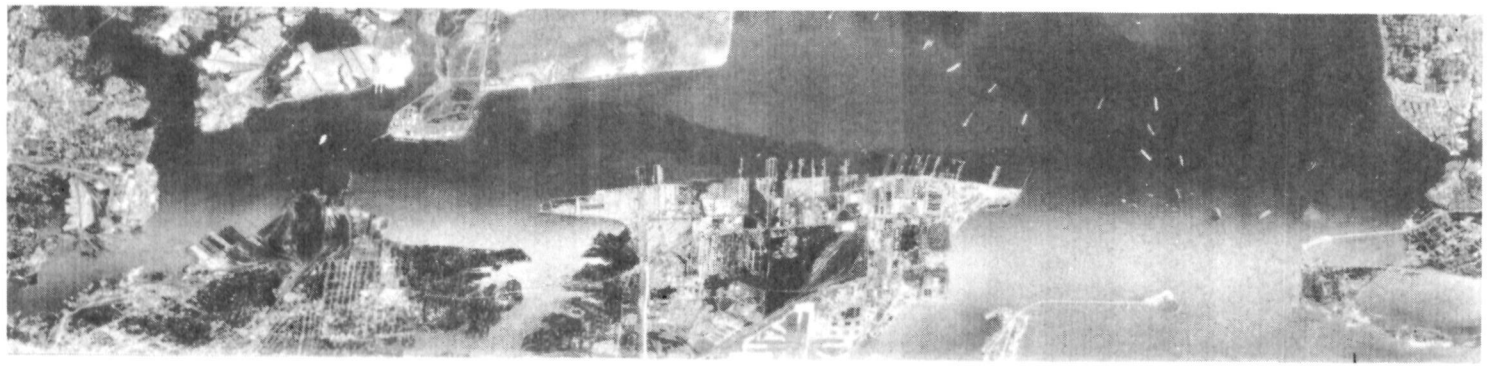
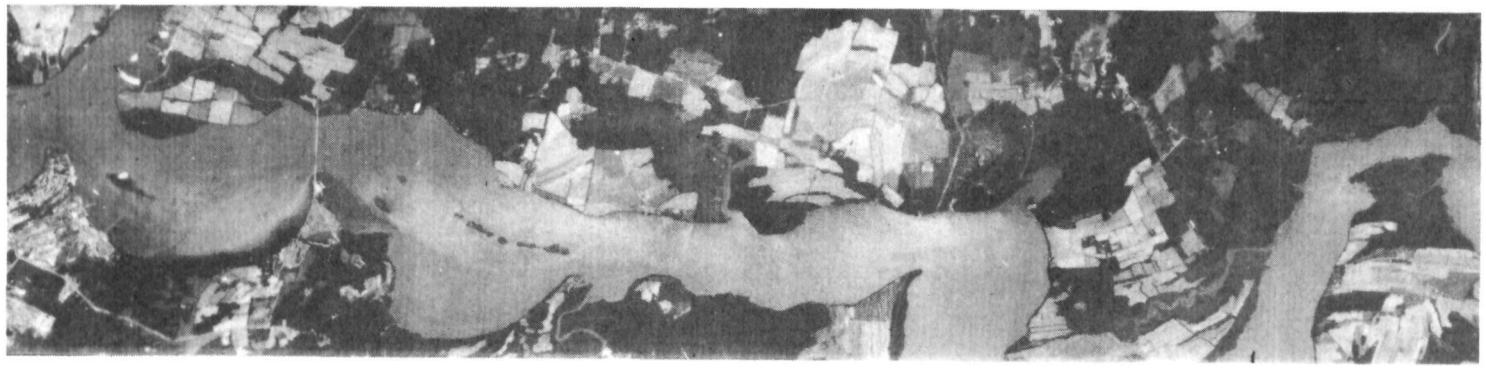


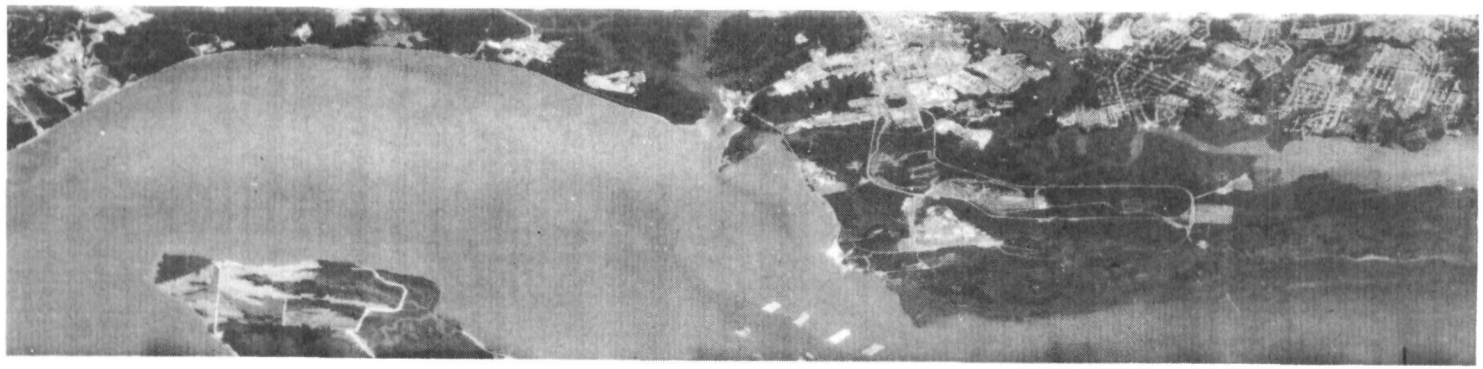
Figure 1. Suspended sediment weight contours for Potomac River, October 11, 1972. (Taken from ref. 3.)



Test site 1, Norfolk.



Test site 2, Hopewell.



Test site 3, Hog Island.

Figure 2. Multispectral scanner (Bendix M2S) imagery of test sites on May 28, 1974. Band 5 (0.58 - 0.62μ) shown.

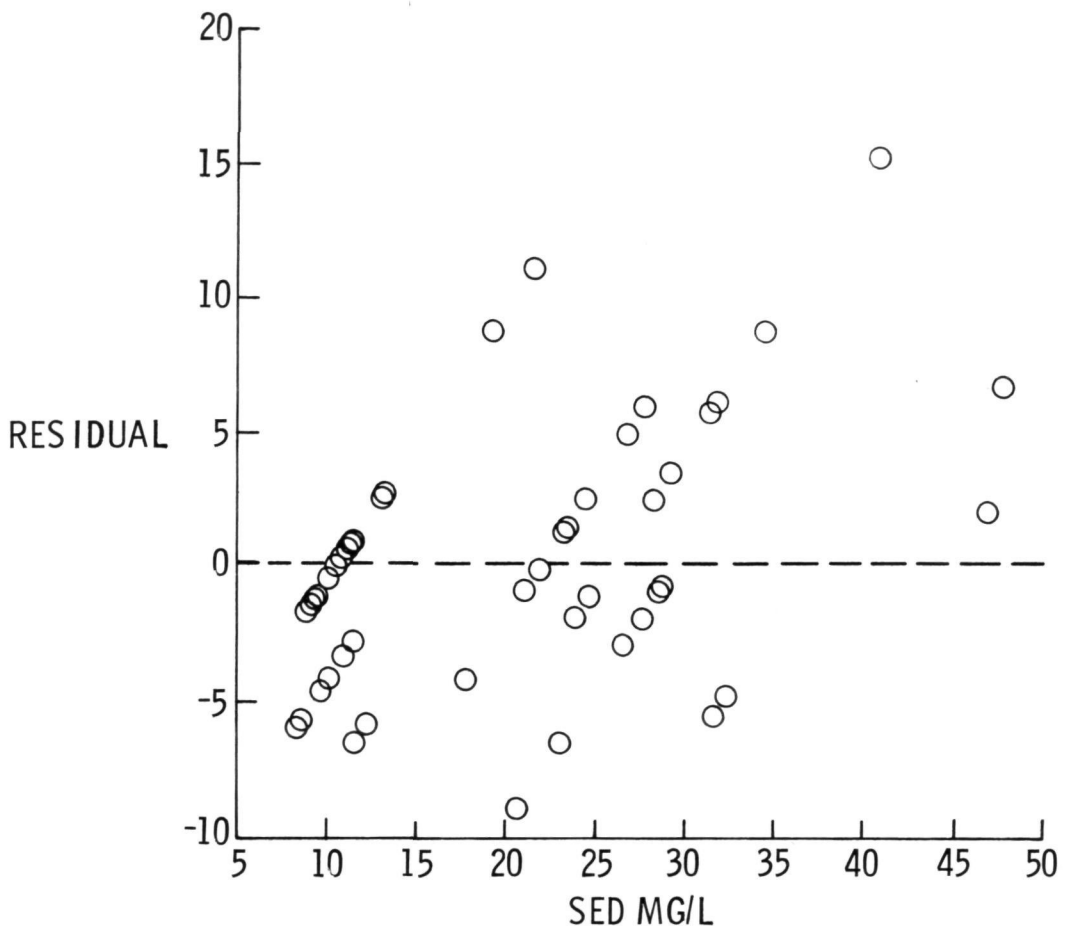


Figure 3. Regression equation residuals (deviations from fitted regression line) as a function of sediment concentration.

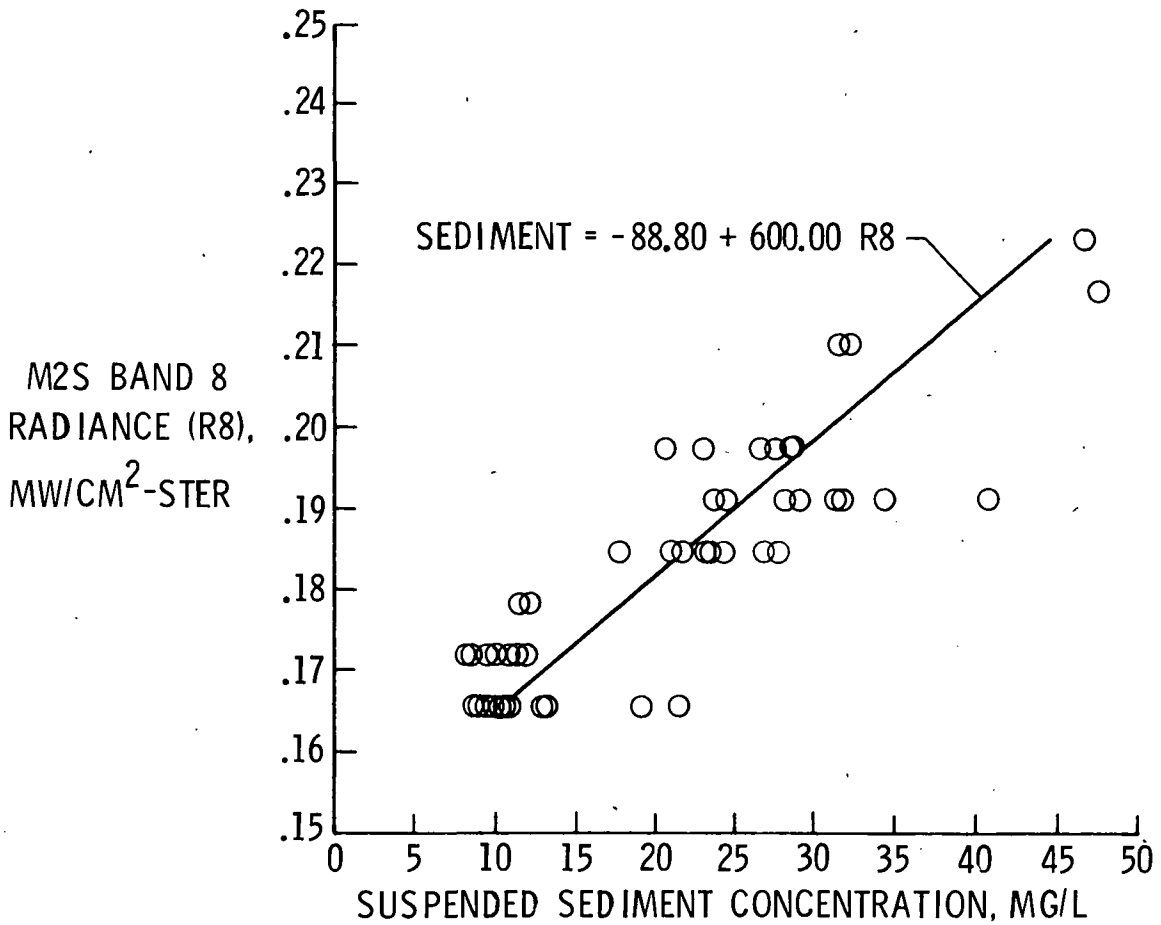


Figure 4. Suspended sediment concentrations, M2S Band 8 radiances and fitted single band regression line.

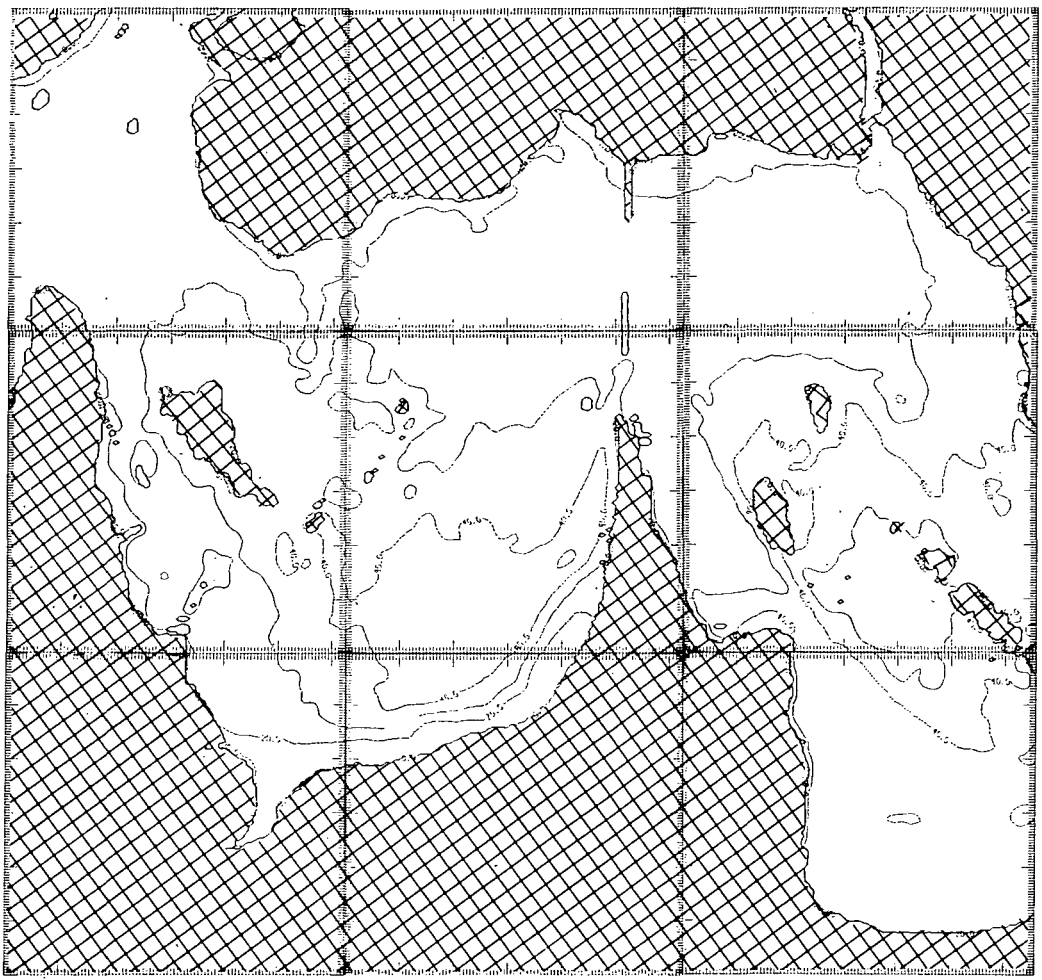


Figure 5. Quantitative suspended sediment contours in the upper James River near Hopewell, May 28, 1974.

REMOTE SENSING OF SALINITY

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ABSTRACT

The complex dielectric constant of sea water is a function of salinity at 21 cm wavelength, and sea water salinity can be determined by a measurement of emissivity at 21 cm along with a measurement of thermodynamic temperature. Three aircraft and one helicopter experiments using two different 21 cm radiometers were conducted under different salinity and temperature conditions. Single or multiple ground truth measurements were used to calibrate the data in each experiment. RMS deviations of between 2 and 3°/oo were found between remote and ground truth boat measurements. Part of this deviation is attributed to position mislocation between the aircraft and boats. It is inferred from these experiments that accuracies of 1 to 2°/oo are possible with a single surface calibration point necessary only every two hours if the following conditions are met--water temperatures above 20° C, salinities above 10°/oo, and level plane flight. More frequent calibration, constraint of the aircraft's orientation to the same as it was during calibration, and two point calibration (at a high and low salinity level) rather than single point calibration may give even better accuracies in some instances.

INTRODUCTION

In a previous paper (Thomann 1973), the variation of the dielectric constant of sea water versus salinity at 21 cm wavelength was investigated. The remote radiometric and ground truth calibration measurements necessary to remotely determine sea water surface salinity were discussed, along with the results of some initial aircraft experiments. Perturbating influences, which limit the salinity measurement accuracy which can be attained with this technique were also covered. This report presents the results of several additional aircraft and helicopter experiments which have been done since 1973. A very brief description of the measurement technique will be given before the experiments are discussed. A reader wishing a more detailed account of the technique itself can consult the above reference.

The dielectric constant of a sea water solution can be approximated by a Debye equation

$$\varepsilon_c = \frac{\varepsilon_s - \varepsilon_\infty}{1 + i\lambda_s^{1-\alpha}/\lambda} + \varepsilon_\infty + \sigma / i\omega\varepsilon_o \qquad (1)$$

in which ε_c is the complex dielectric constant of the solution. ε_s is its low frequency value, and ε_∞ its high frequency value (both real). λ_s is the relaxation

wavelength, α is a spread parameter used to make slight adjustments to the value of ε_c, λ and ω are wavelength and radian frequency, σ is the ionic conductivity of the solution, and ε_o is the permittivity of space. λ_s, ε_s, σ, and α are functions of salinity and temperature.

For a complex solution such as sea water, the parameters (except for the conductivity σ) have not been known as a function of salinity and temperature and values obtained from a NaCl solution are usually substituted. Since the salt content of normal sea water is 78% NaCl this substitution results in a fairly accurate approximation, especially since the sea water conductivity, which is known, has the major effect upon the change in ε_c as salinity and temperature vary. In our experiments, the actual conductivity of sea water is used and values derived from NaCl solutions are used for the other parameters. Recently, direct measurements of the dielectric constant of sea water have been made (Ho, 1974), but these results have not been incorporated into the Earth Resources Laboratory (ERL) equations.

The last term in Eq. (1) determines the frequency range in which the salinity of sea water can be measured. At frequencies above about 3 GHz, the term is inconsequential (for this purpose). As wavelengths become longer, another factor enters; very large antennas are required to obtain any pointing ability. A radio astronomy band exists from 1.400 to 1.427 GHz, which is in the required frequency range and is also fairly free from man-made radiation. As a result, it is a good choice for remote salinity sensing and is used in our experiments. At this frequency, an antenna about one meter square is required to obtain a 15° half power bandwidth.

The apparent temperature of the water at 21 cm wavelength can be determined from its emissivity for any thermodynamic water temperature. Fig. 1 shows the variation of 21 cm apparent temperature versus salinity for several water temperatures. The emissivity used to construct this figure was derived from the dielectric constant using the Fresnel equation for reflection from a plane surface. The possible salinity measurement accuracies can be determined from this graph; the best accuracies are obtained for higher salinities and higher temperatures with little sensitivity available at salinities below 10°/oo except perhaps at the higher water temperatures. A reasonable goal turns out to be a 1-2°/oo accuracy measurement for salinities above 10°/oo and water temperatures above 20°C.

A remote system for measuring salinity requires a measurement of apparent temperature at 21 cm wavelength (or some nearby wavelength) and a measurement of the thermodynamic temperature. This second measurement can be done in any region where the dielectric constant is known; in the ERL experiments the measurements are done at 8-14 μm, but measurements in other regions could be done as well.

Because of the 1-2°/oo sensitivity of this technique, it would appear doubtful to be of use in the deep oceans where usually only small salinity changes occur. For anomalous larger changes, this would not necessarily be the case. Because of the large salinity changes which normally occur along coasts, the technique is more suited to these regions. Since land is radiometrically much hotter than water at 21 cm wavelength and because antenna beamwidths are limited by the combination of long wavelength and feasible antenna size, low altitudes are usually dictated. Most ERL experiments to date have been flown at 800 ft. The 21 cm antenna is pointed from 5 to 15° forward of vertical incidence in the ERL experiments. Fig. 1 is for a 9.3° incidence angle, which happened to be the angle used in one of the earlier ERL experiments. Larger sensitivities actually exist for larger incidence

angles. For instance, at 30°C water temperature, the difference in 21 cm apparent temperature between water of 0°/oo salinity and 35°/oo salinity is 30°K for a 55° incidence angle, and is 25°K for a 30° incidence angle. For zero degree incidence angle, the difference for the same salinity range is only 23°K. However, at the larger incidence angles, the variation of 21 cm apparent temperature with antenna incidence angle is much greater than at the smaller angles and variations in the pointing angle of the antenna can cause significant errors. As an example, at a supposed 30° incidence angle, a pointing angle error of one degree will cause a salinity calculation error of 1.3°/oo. At 10° incidence angle, the same error will effect the salinity by a .4°/oo and at 5° the error will be only .2°/oo.

Another problem with large incidence angles is that the area being sensed is not directly under the aircraft, which is the area most other instruments sense. For these reasons, temperature measurements for salinity are usually not made at extreme incidence angles.

For a different reason, incidence angles of zero degrees are also usually not used. At zero degrees, the reflection of the hot aircraft off the sea surface would be seen by the 21 cm antenna. A large plane with, for instance, a wingspan of 100 feet might raise the apparent temperature by about 3°K if the antenna had a 15° beamwidth and the aircraft altitude was 800 ft. If the reflection of the plane could be considered to emanate from a large number of independent statistical emitters of comparable amplitude on the surface of the sea (much as many area extensive targets are treated in certain types of scattering problems) then the post detection bandwidth provides enough averaging to allow only a small variance and the 3°K offset would be removed in the calibration. However, it is not certain that the aircraft's reflection behaves in this manner. Random motions of aircraft orientation and the non-smooth surface of the sea might cause variations of a slow enough nature that they would not be filtered. Because of this possible reflection problem, the antenna is tilted far enough forward (in our case 5-15° angles have been tried) to remove most of the aircraft reflection from the antenna in the ERL experiments. With a smaller aircraft, the reflection would not be as severe and operation directly under the plane might be optimum.

The vertical component of the upwelling radiation is the only component sensed for salinity calculations, because the horizontal component is much more susceptible to variation with wind speed than the vertical (Paris, 1971). For this reason, Fig. 1 shows variation for vertically polarized radiation.

Some superfluous radiation always enters the radiometers; galactic radiation and solar radiation reflecting off the sea surface are the main outside sources of error for the 21 cm measurement, while the atmosphere is the main problem with measurements in the thermal infrared. Instrument offsets are always a problem in both bands. The errors in the radiometric measurements are corrected from one or more ground truth measurements. A simple offset correction obtained from one position usually suffices for the 8 - 14 μm measurement. An offset correction will also suffice for the 21 cm measurement if the gain of the 21 cm radiometer is trusted, since the other errors appear mainly as an offset. If the radiometer gain is not trusted, which was the case during the first ERL experiments, then a two-point correction is required which involves both an additive and multiplicative adjustment to the data. During later ERL experiments, only a single offset correction was used for the 21 cm data.

After corrections are applied to ι data from the calibration points, the raw data is converted to salinity by matching the measured emissivity at 21 cm and measured thermodynamic temperature to a matching salinity.

Flight Line for Aircraft Experiments

The flight line shown in Fig. 2 was selected for the aircraft experiments. This line is off the Gulf Coast of Louisiana and Mississippi and extends at the west end, from waters near Lake Pontchartrain where considerable fresh water flows into the Gulf, eastward into the Gulf outside the barrier islands where the salinity more closely approaches that of oceanic values. Because most of the fresh water input in this area of the Gulf is at the western end of the line, and because of the mixing influence of the tides, there usually exists a fairly constant salinity gradient along the line, although the absolute salinity value may vary quite markedly according to recent precipitation and river level conditions. Except for the presence of quite a few land masses near the western end of the line, this line was originally thought to be ideal for testing. Unexpectedly, the fairly constant salinity gradient has caused problems, which will be discussed below.

August 25, 1972 Aircraft Experiment

On this date, the line in Fig. 2 was flown six times, three in each direction by the NP3A NASA Earth Resources aircraft. The altitude was 800 ft (244m). The antenna incidence angle was 10°; only vertical polarization radiation was received. The experiment was flown between 1645 and 1800 CDT. The L-band channel of the Multi-Frequency Microwave Radiometer (MFMR) a four channel NASA radiometer, measured the apparent temperature of the sea surface at 21 cm and a PRT-5 measured apparent temperature at 8-14 μm. Surface salinities varied from about 10°/oo at the western end of the line to about 30°/oo at the eastern end. These salinities are somewhat high for this line and are due to the dry conditions which had been experienced during the time preceding the experiment. Stationary boats were located at the three circled positions shown in Fig. 2. On each run the aircraft flew directly over each of these three boats to provide time markers on the photography which was taken coincidentally with the radiometric data. A moving boat traversed the line during the experiment and took ground measurements at approximately one mile intervals. The sampling positions were located as closely as possible using a LORAN system. The running boat was to traverse the entire line, but darkness halted it at position 17. Water temperatures were quite warm, about 30°C. In 1972, there was little confidence in the MFMR as an instrument and two ground truth points were used to correct each run of the 21 cm data before salinity processing. That is, both a translation and a rotation of the data plotted two dimensionally as amplitude versus time was made.

Fig. 3 shows the remotely measured salinity for each of the six runs, the salinities measured by the three stationary boats and the salinity values measured by the moving boat. Stationary boats 1 and 3 were used to calibrate each remote measurement run individually. The accuracy obtained using stationary boat 2 and the values from the moving boat for error calculation was about 2°/oo. Processing was also done using the scale factors calculated for line 3 to process data from the complete mission. The accuracy in this case was about 2.5°/oo. A more complete discussion of this experiment is given by Thomann (1973a).

November 7, 1973 Experiment

Experiments previous to the August 25, 1972 experiment had shown that MFMR yielded quite variable results and the operation of the radiometer during the August 25 experiment was much better than had been experienced before. For additional information on previous results obtained from the radiometer see

Thomann (1973). Previous to the November 7 experiment, ERL requested that the L-Band channel of the MFMR be upgraded to improve its sensitivity and stability. The instrument was overhauled by Johnson Space Center engineers. Improvements included a new antenna, and improvement of the receiver electronics, the noise reference sources and the calibration procedures. The improvements to the L-band channel of the MFMR are documented by Reid (1973).

On November 7, the line, shown again in Fig. 4, was flown eight times, four times in each direction at an altitude of 800 ft. (244 m). The antenna was pointed 15° forward of vertical; only the vertical component of radiation was received. The PRT-5 was used to measure water temperature. The experiment started at 1130 and ended at 1400 CST. Three stationary boats were located at the positions shown in Fig. 4. A moving boat took ground measurements at the positions 1-26; the measurements at positions 20 and 21 were later thrown out because they were too close to Grand Island, a small grass island and the 21 cm data was contaminated at these points. The water temperature at the time of the experiment was about 20°C, which is near the lower limit for effective remote measurement of salinity, so reduced sensitivity could be expected and very poor performance in the 0 to 10°/oo range could be expected.

More confidence in the MFMR existed after the modifications and for this experiment only an offset was added to the 21 cm data. This offset was calculated from a measurement at stationary boat 3 as the NP3A passed over it on run 1. The remotely measured values of salinity, the measurements at the stationary boats, and the measurements taken by the moving boat are shown in Fig.'s 5 - 8 for runs 1, 4, 6, and 8, which are representative of the eight runs. By the time of this experiment, a computer program had been written to generate the graphs instead of hand drawing them as was previously done. All information except the position and measured salinity values obtained by the running boat are computer plotted. The moving boat information was still plotted by hand.

The overall RMS accuracy for the experiment was 3.6°/oo, which was at first glance disappointing. However, much of the error occurs along the parts of the line where the salinity is low and poor accuracies would be expected. In addition, it is believed that some land interference may be occurring along the western end of the line, which would cause the numerous zero salinity readings seen in Fig.'s 5 - 8. If the accuracy is calculated only along the section of the line where the salinity was 10°/oo, the composite accuracy is 2.7°/oo, which is considerably better.

One problem in calculating the accuracy of the remote measurements is uncertainties in the aircraft position. It is always impossible to locate exactly the position of the plane with time. Internal navigation systems are not as accurate as required and photography only provides time-marks at landfalls and over the stationary boats. Also, it is impossible to locate the position at which the moving boat made measurements with an average accuracy much better than about a quarter of a mile. Along a line with a constantly changing salinity, the result is that each mislocation between the aircraft and ground truth position contributes (statistically, at least) to the calculated RMS error. One particular place during this experiment where such a possible discrepancy can be noticed is the sharp drop in salinity from about 30°/oo to about 20°/oo which can be seen in the figures. In this area there is a marked difference in the remote and ground truth salinity even though the salinity variation follows the same pattern. This marked difference could be caused by a displacement in the estimated positions of the aircraft and the boat. If this area of very rapid change is removed for the error calculations, the overall accuracy comes out to be 2.2°/oo, which is respectable.

As mentioned previously, the aircraft attempts to fly directly over the stationary boats on each pass to provide time markers on the plane's location. On November 7, there was considerable fog and often some rather quick turns had to be made to pass over the boats. As discussed before, the apparent temperature of the sea surface depends upon incidence angle and the banking during turns thus resulted in a change in the remotely sensed salinity. Examination of the photography sun glint patterns were made to determine the times at which the aircraft banked; the difference between the remote and ground truth salinities at these times were examined. Large errors at these times were found, which undoubtedly contributed to the overall RMS accuracy attributed to the experiment. No attempt was made to remove that data taken at the time the plane was turning and recalculate the error. It was felt that continuation in this vein was going to eventually disqualify all data taken. It is important to point out these problems which cause errors in the remotely sensed salinity because they can often be corrected with careful planning. In this case, they arise simply because it is being attempted to evaluate the technique, and very high fidelity "truth" data is needed which will not be needed in large quantities with operational use of such a system after it has been proven.

As a final accuracy check, without recourse to the ground truth data, the remote data standard deviation was calculated at each boat position where the salinity was greater than $10^{o}/oo$. The salinity changed very little during the experiment, hence the remote measurement should be the same at each point on each run. If it is assumed that the remote measurement is an unbiased statistical estimator of the salinity, then the standard deviation can be considered to be the RMS error. The average standard deviation was $1.3^{o}/oo$, which is quite good. One contributing effect still not removed from this error figure, however, is the fact that it is impossible to precisely locate the plane on each run and hence the standard deviation was not calculated at the exact same points on each run.

Several conclusions were drawn from this experiment. The first was that it is impossible to exactly determine the remote measurement accuracy using for a test area a line with a nominally constant salinity gradient, because ground truth and aircraft location problems contribute too much intrinsic error to the experiment. The type of line that is needed for an evaluation experiment is one where the salinity changes in unit steps and stays constant between these impulse changes. Such conditions are unfortunately hard to find in natural circumstances. Another testing method would be to use a large number of stationary boats and fly directly over them using the coincident photography to determine the passover time. Unfortunately, such types of experiments are expensive.

Despite the inability to exactly determine the remote accuracy, it was felt that the experiment did provide enough accuracy data to make a definite statement about operational use of the technique. It was felt that operational remote salinity measurement with an accuracy of $1 - 2^{o}/oo$ was possible if the following conditions were observed:

1. Ground truth calibrations about every two hours at locations well removed from land contamination (a mile or two).

2. Operation in warm (20-30°C) fairly saline (above $5-10^{o}/oo$) water with decreasing accuracy expected for colder or fresher water. The low salinity limit of the technique is not exactly specified because it is temperature dependent.

3. Insurance that all data used was taken when the aircraft was flying level.

If desired, a more detailed discussion of the November experiment is given by Thomann (1975).

June 4, 1974 Aircraft Experiment

The June experiment was conducted virtually identically to the one that preceding November. Unfortunately, this experiment was conducted before the data from the November experiment was processed, so the same measurement difficulties are inherent in the experiment, i.e., the problems of plane and boat position alignment and aircraft banking were still experienced. In addition, there was a considerable overall salinity change in the test area during the course of the experiment which adds a further error to the remote salinity accuracy determination. The aircraft takes several measurements at each point, while the moving boat has time during the experiment to run the line only once and the values it measures must be used during the entire time of the experiment. As a result, ground truth taken by the moving boat gradually loses its fidelity for evaluating the remote measurement, the loss being proportional approximately to the difference in time between the remote and aircraft measurement.

This experiment was conducted from 1630 to 1845 CDT. The flight line, the positions of the stationary boats, and the positions where measurements were taken by the moving boat are shown in Fig. 9. To demonstrate the salinity change that occurred during the experiment, the salinity dropped from 22.4°/oo to 20.0°/oo at stationary boat 3 during the course of the experiment, from 10.4°/oo to 8.9°/oo at boat 2, and from 2.3°/oo to 1.8°/oo at boat 1. This change was unexpected since during the previous experiments along this line the salinity change was rarely over .1°/oo during the entire experiment.

The line shown in Fig. 9 was flown eight times, four times in each direction. The first run was from east to west, with subsequent runs in alternate directions. The incidence angle of the 21 cm antenna was 10°, with vertical polarization received. The water temperatures were warm at this time of the year, running about 30°C. The water was quite fresh, varying from virtually fresh water at the west end of the line to about 20°/oo at the eastern end. The running boat started at the western end of the line at the beginning of the experiment and took measurements at positions 1-24 shown on Fig. 9. Although the seas were calm at the beginning of the experiment, surface conditions deteriorated as the experiment progressed and the moving boat was forced to quit at position 24 before the complete line was traversed. This was unfortunate since it is the eastern measurements which are most important for the experiment since this is the more saline end of the line.

Representative plots of the remotely calculated salinity, the measurements by the stationary boats and the moving boat are shown in Fig.'s 10, 11, 12, and 13, for runs 1, 4, 5 and 8. As before, the remote salinity values and the stationary boats' positions and measured salinity value are computer plotted; the positions and salinity values measured by the moving boat are hand drawn. Calibration was established at a single point, as the aircraft passed over boat 3 on run 4, which was the midpoint of the mission. The overall accuracy for the complete experiment was 3.64°/oo. Most of this error occurs at the western end of the line, where the fresh water occurs and also where there are numerous land areas near the flight line. The numerous zero salinity readings occurring both during this experiment

and the November 7, 1973 experiment at the western end of the flight line lead to the suspicion that with the new antenna mounted in the aircraft some side lobes exist which affect the system performance when the plane is oriented unfavorably to an adjacent land mass. Since land virtually encircles the aircraft at the western end of the line, it is not possible to tell which orientation this is. For that matter, it is also impossible to form more than a suspicion about the side lobes of the antenna since the water at the western end of the line is so fresh that little sensitivity is expected anyway. When not in the aircraft, the antenna pattern supposedly shows no anomalies, but the pattern of the antenna mounted inside the nose of an aircraft can be quite different than it exhibits on an isolated mounting.

As for the November experiment, the accuracy improves markedly when only the higher salinities are considered. For salinities greater than $9^{o}/oo$, the overall accuracy for the eight lines is $2.3^{o}/oo$. This error figure includes the problem of locating the aircraft and moving boat exactly, some plane banking, the fact that the overall salinity changed during the mission which degrades somewhat the measurements taken by the moving boat which are used in the error calculation, and the fact that the water was unusually fresh so even at the saline end of the line the sensitivity was not as high as it would be on other experiments involving saltier water. Statistically, it is possible that all these factors would affect the error calculation favorably, but that is extremely unlikely, and it is felt that the actual remote measurement accuracy is somewhere between 1 and $2^{o}/oo$.

Additional examination of the accuracy calculations yields more insight into possible accuracies. The calibration was done as the plane passed over boat 3 on run 4. Runs 2, 4, 6, and 8 were all in the same direction (west to east), while runs 1, 3, 5, and 7 were all east to west. The composite accuracy for the even numbered lines for salinities greater than $9^{o}/oo$ was $1.8^{o}/oo$, while the composite accuracy for the odd lines $2.6^{o}/oo$. This difference in accuracies would indicate that the best results will be obtained when the aircraft is flying in the same orientation that it was in when calibration was established. This is a reasonable result since, because the radiometer antenna is not pointed directly below the aircraft, differing amounts of galactic and solar radiation will be reflected into the antenna as the aircraft changes direction. In this instance, only four lines in each direction, no general statement can be made, especially since at this time a separate calibration has not been established for the odd lines to see if a corresponding accuracy with the even lines would result. In addition, because of considerable surrounding land masses, and possible side lobes in the antenna pattern, the east to west lines may simply provide less accuracy than the west to east lines because of land contamination.

The accuracy for line 4 was the best of all runs, $1.2^{o}/oo$, which is again a reasonable outcome since it is the closest even numbered line to the calibration time. Again, no conclusion can be drawn since individual calibrations have not been established for each line to optimize them. In any case, even individual calibration might not provide any definitive basis for conclusions since the water salinity changed during the course of the experiment and the ground truth fidelity varies with time.

It is thought that the results of this experiment support closely those already listed after the November 7 experiment, and, consequently, lend more weight to them. The additional information gathered from this experiment is an indication that for best results the plane orientation should be kept the same as it was during calibration.

HELICOPTER EXPERIMENTS

The helicopter experiments were conducted with a separate radiometer purchased by ERL. The purposes of conducting experiments with another radiometer were to see if the results obtained with the MFMR on the NP3A could be duplicated and also eventually to install this newer radiometer on a smaller aircraft which would be an easier and less expensive aircraft to use. The ERL instrument is a Dicke type null balancing radiometer. The antenna is approximately one meter square and is capable of receiving only a single linear polarization at any one time.

The radiometer antenna was mounted beneath a NASA Bell Jet Ranger helicopter with the receiver mounted within the helicopter for the experiments.

April 16, 1974 Helicopter Experiment

The line shown in Fig. 14 was flown four times, twice in each direction. The line that was used for the aircraft experiments was not used with the helicopter because the limited range of the helicopter did not allow it. The helicopter altitude was 800 ft., the antenna incidence angle was 10° forward, and vertical polarization was received. The experiment was conducted between 1430 and 1600 CDT. Three stationary boats were located at the positions shown in the figure, which the helicopter was to pass directly over on each run, and a fourth boat moved between boats 2 and 3 taking salinity and temperature measurements as close to every mile as possible. The fourth boat could not run the entire line because of areas of shallow water between boats 1 and 2.

The overall accuracy for the experiment was 1.4°/oo, with the accuracy being calculated from the measurements taken by the moving boat. The same problems which existed during the aircraft experiments, i.e, the inability to exactly locate the position of the helicopter and the moving ground truth boat also occurred during this experiment, but probably had little effect upon the data because the water through which the fourth boat moved was of fairly constant salinity, varying only from about 20°/oo to 15°/oo. The salinity did not change significantly during the experiment. A single calibration point was established for each line, as the helicopter passed over boat 3. The salinity plots for runs 1 and 4 are shown in Fig.'s 15 and 16, respectively. It is evident from these plots that in almost every instance, as the helicopter passes over one of the stationary boats the salinity drops precipitously, which is due to the fact that the boat is radiometrically much hotter than the surrounding water and its contribution raises the perceived 21 cm temperature and hence lowers the salinity. Because of this effect, the calibration of each run was not done using the radiometric data acquired directly over boat 3, but with data acquired to one side or the other of the boat which was not contaminated. This effect did not occur during the aircraft experiments because the aircraft velocity is much higher than that of the helicopter and the long post detection averaging time used filtered out the effect of the boat. The slower helicopter is over the boat long enough for its effect to be felt even after post detection averaging.

It can also be seen from the two figures that while the instrument gain is close to correct on run 4, the gain (voltage out vs. power in) of the radiometer is markedly off on run 1. The salinity is correct at boat 3 where the calibration was done (it has to be, by definition) but is quite high as the helicopter passes boat 2 (disregarding the boat induced spike which almost certainly is correct only by coincidence) and is about 10°/oo high over boat 1. The same gain function is

used throughout the experiment for calculating the salinities, so it is obvious that the gain of the radiometer has drifted during the experiment. This is not alarming--the radiometer itself was still very new and could still have had minor defects inherent within it which have not yet been corrected. Also, it had only recently been installed on the rather hostile helicopter environment. The gain problem might arise simply because the instrument was not properly warmed up when the experiment started, which would account for the poor performance on run 1 and the much better gain performance on run 4. Examination of runs 2 and 3 show a slight trend in instrument performance improvement with time, but not enough to state that the warm up problem is the cause. Whatever the cause of the gain drift, if the instrument were to be operated on the helicopter permanently, it would have to be solved if single point calibration were to be used. Since the helicopter was only a temporary platform for the radiometer, no solution to the drift problem was sought. After the radiometer is installed on a small aircraft, if gain drift problems continue, they will then have to be addressed. A two-point calibration could be done on run 1 to force the salinity to be correct at both boats 3 and 1. This was not done because it is not anticipated that two point calibration will be used with this radiometer in the future. As stated above, if any gain drift problems persist after aircraft installation, they will be addressed and solved. There is also a danger in using boat 1 for a calibration point because of its close proximity to land and the possibility of contamination from land radiation. This is often a problem with two point calibration; if the calibration is to be effective, the salinities of the two points must be markedly different, and it is often difficult to find a fresh water calibration point that is not near land.

A second helicopter experiment similar to the April 16 experiment has also been done, but the plots of the remote and surface salinity were not completed in time for this paper. The accuracies obtained in this second experiment were close to those of the April 16 experiment; in addition, the gain problem was not as noticeable during this second experiment.

DISCUSSION AND SUMMARY

The results of several aircraft and helicopter experiments have been presented. In most cases, single point calibration was used, using either a single calibration point for a whole experiment, or, in the helicopter experiment outlined, a single calibration point was used for each line. For the first aircraft experiment of August 25, 1972, two point calibration was used on each line, but this was before the MFMR was rebuilt, and later experiments showed that single point calibration gave quite good results after the MFMR improvement.

In the instances where ground truth was available over a considerable salinity range, the remote accuracies usually varied from 2 to 3°/oo. Part of this error is due to the problems of matching aircraft and ground truth boat locations, so the actual error attainable remotely has been inferred to be between 1 and 2°/oo. Fairly consistent results were obtained using two separate radiometers, one mounted on the aircraft and the other on a helicopter. Some gain problems were noted in the radiometer on the helicopter experiments, but it is felt that these problems are due to the newness of the radiometer and the fact that it was only recently installed on the helicopter for tests. In general, it is thought that the results obtained from the experiments with the two radiometers support each other in determining the accuracies obtainable remotely. It is presently felt that the following list describes accuracies and constraints for operational use of a remote salinity measuring system in the microwave region.

1. Accuracies of 1 to 2°/oo with single point calibration about every two hours.

2. Water temperature above 20°C, and salinity levels above 10°/oo with reduced accuracies for lower salinity levels.

3. Insurance that all data is taken with the aircraft flying in a level position.

In addition to these listed conditions, there are other situations which are assumed will be avoided, e.g., specular reflection from the sun, heavy sea states, very large clouds, and proximity to land. The effect of these conditions are treated more fully by Thomann (1973).

Slight improvements in accuracy should be obtained with some refinements in the measurement technique, although at the present time it is not possible to estimate what degree of accuracy improvement will result from each refinement. The more constrained conditions of operation are:

1. Hold the aircraft orientation to be the same as it was when the calibration was established.

2. Calibrate the remote data more frequently than once every two hours.

3. Use two point calibration in situations where it is applicable, that is, when homogeneous areas of markedly different salinity exist which are free from land or other contaminating factors.

REFERENCES

Ho, W.W. (1974), "Measurement of the dielectric properties of sea water at 1.43 GHz," NASA CR-2458, Rockwell International Corp., Downey, Calif.

Paris, J.F. (1971), "Transfer of thermal microwaves in the atmosphere," Texas A & M University, College Station, Texas.

Reid, S. (1973), "Multifrequency microwave radiometer (MFMR) L-Band modification," Lockheed Electronics Co., Houston, Texas.

Thomann, G.C. (1973), "Remote measurement of salinity in an estuarine environment," Remote Sensing of Environment 2, 249-259.

Thomann, G.C. (1973a), "Remote measurement of salinity: repeated measurements over a single flight line near the Mississippi Sound," ERL Report No. 079, Earth Resources Laboratory, Bay St. Louis, MS.

Thomann, G.C. (1975), "Testing of a technique for remotely measuring water salinity in an estuarine environment," ERL Report No. 118, Earth Resources Laboratory, Bay St. Louis, MS.

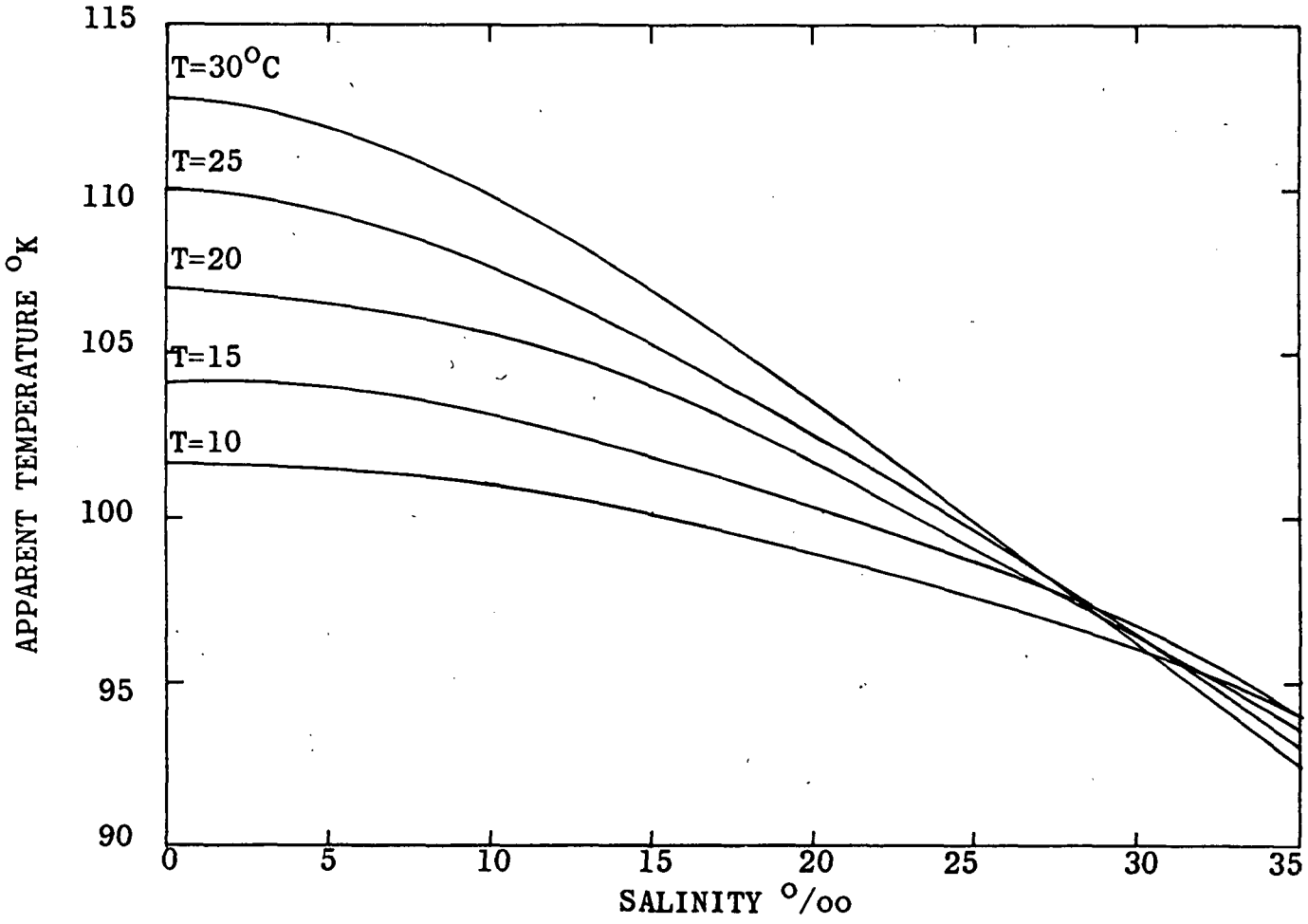


Figure 1. Apparent sea surface temperature at 21 cm wavelength as a function of salinity and water temperature--9.3° incidence angle, vertical polarization, plane sea surface.

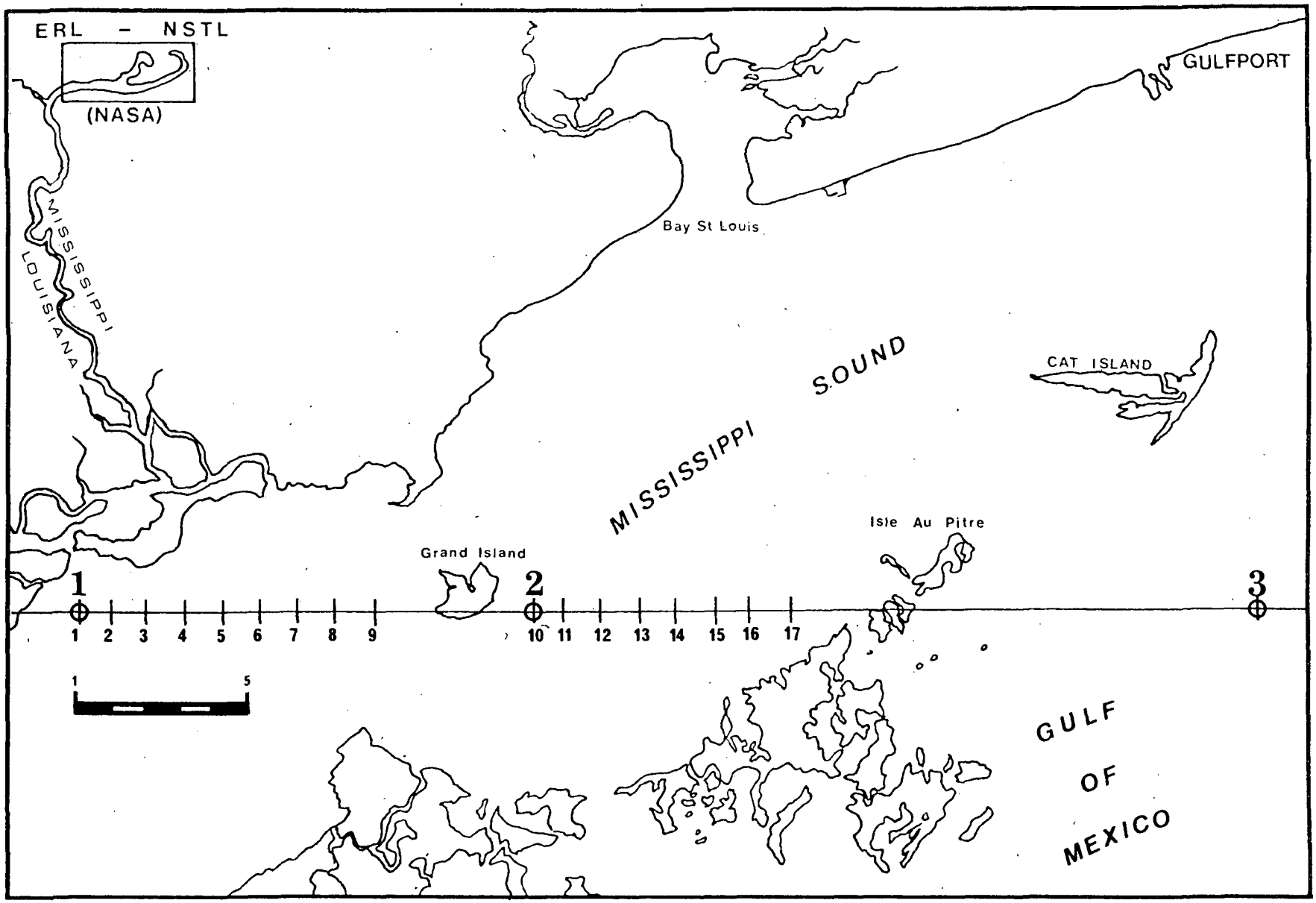


Figure 2. Flight line, stationary boat positions(circled), and moving boat measurement positions for August 25, 1972 experiment

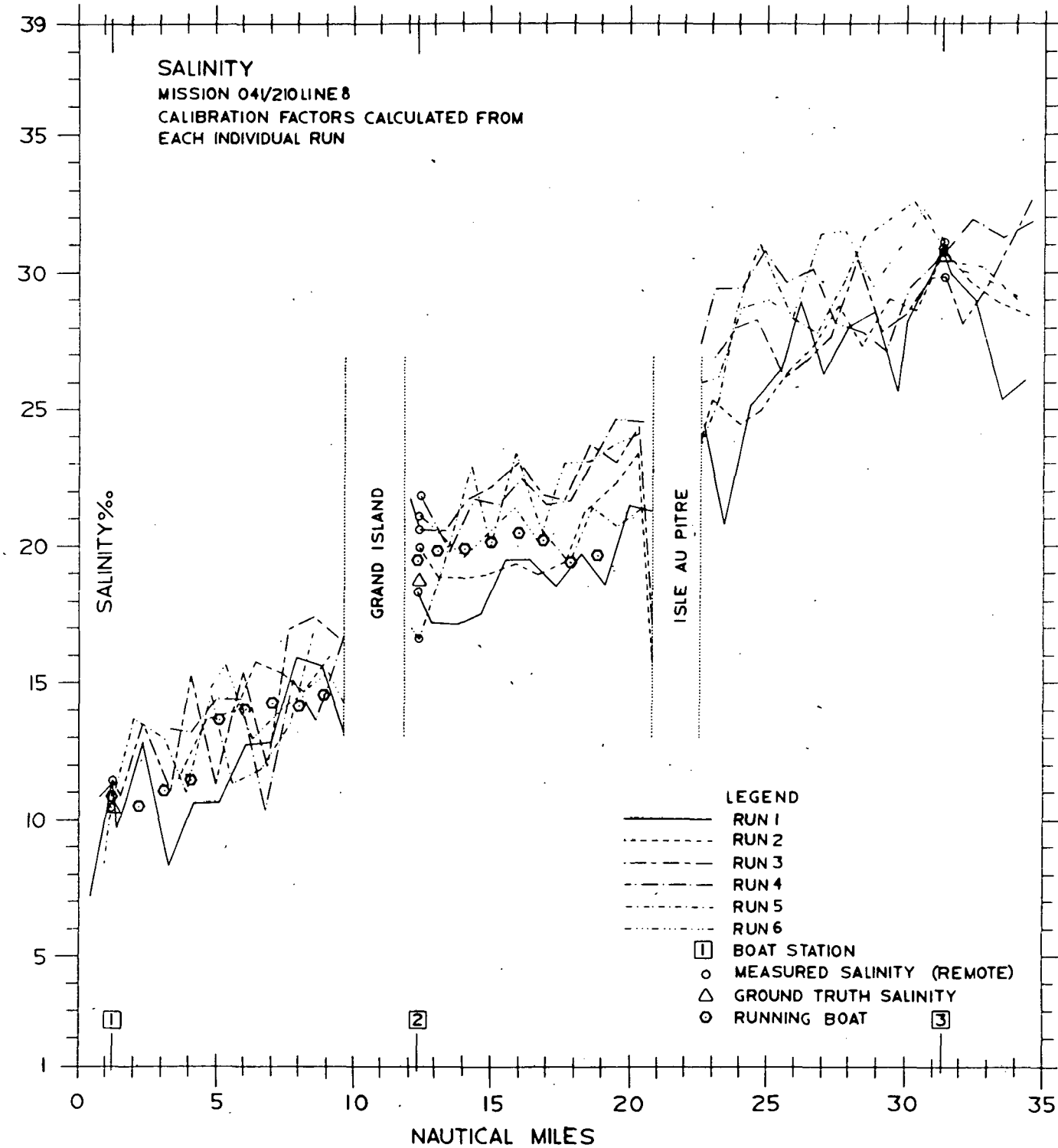


Figure 3. Remotely measured salinity values for the six runs, stationary boat and running boat measured salinity values for the August 25, 1972 experiment.

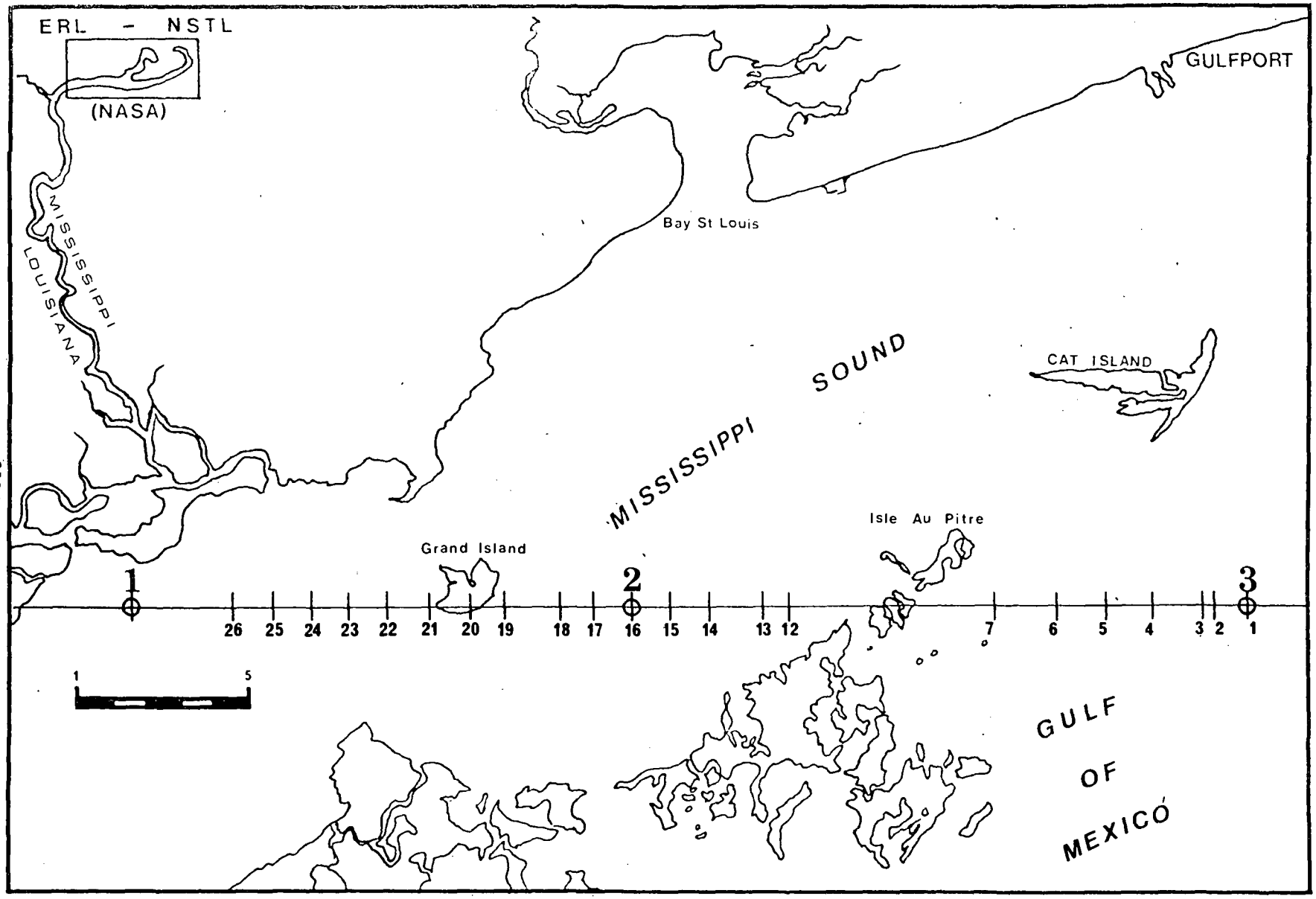


Figure 4. Flight line, stationary boat positions(circled), and moving boat measurement positions for November 7, 1973 experiment

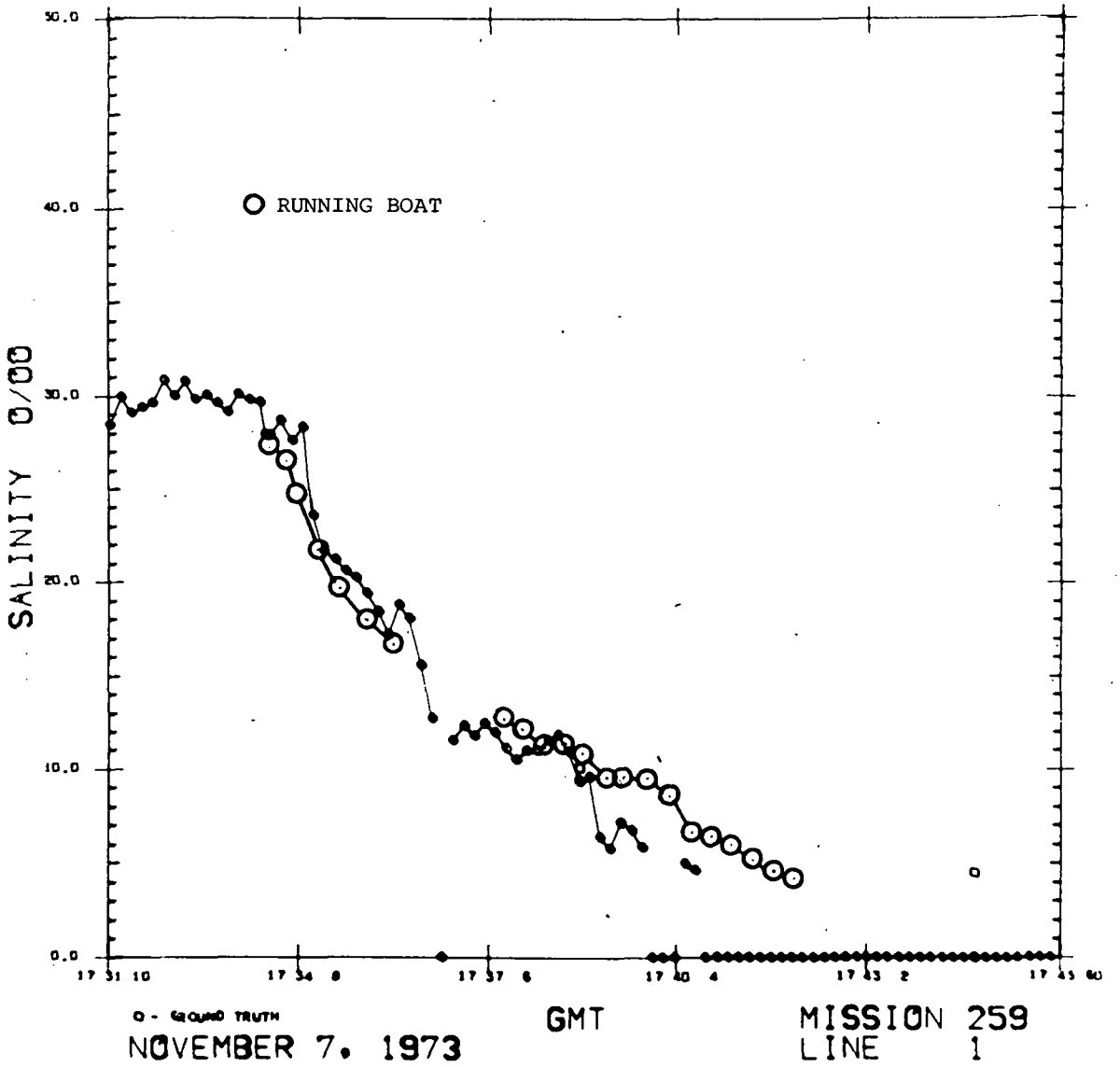


Figure 5. Remote and surface measured salinity values for run 1 of the November 7, 1973 experiment.

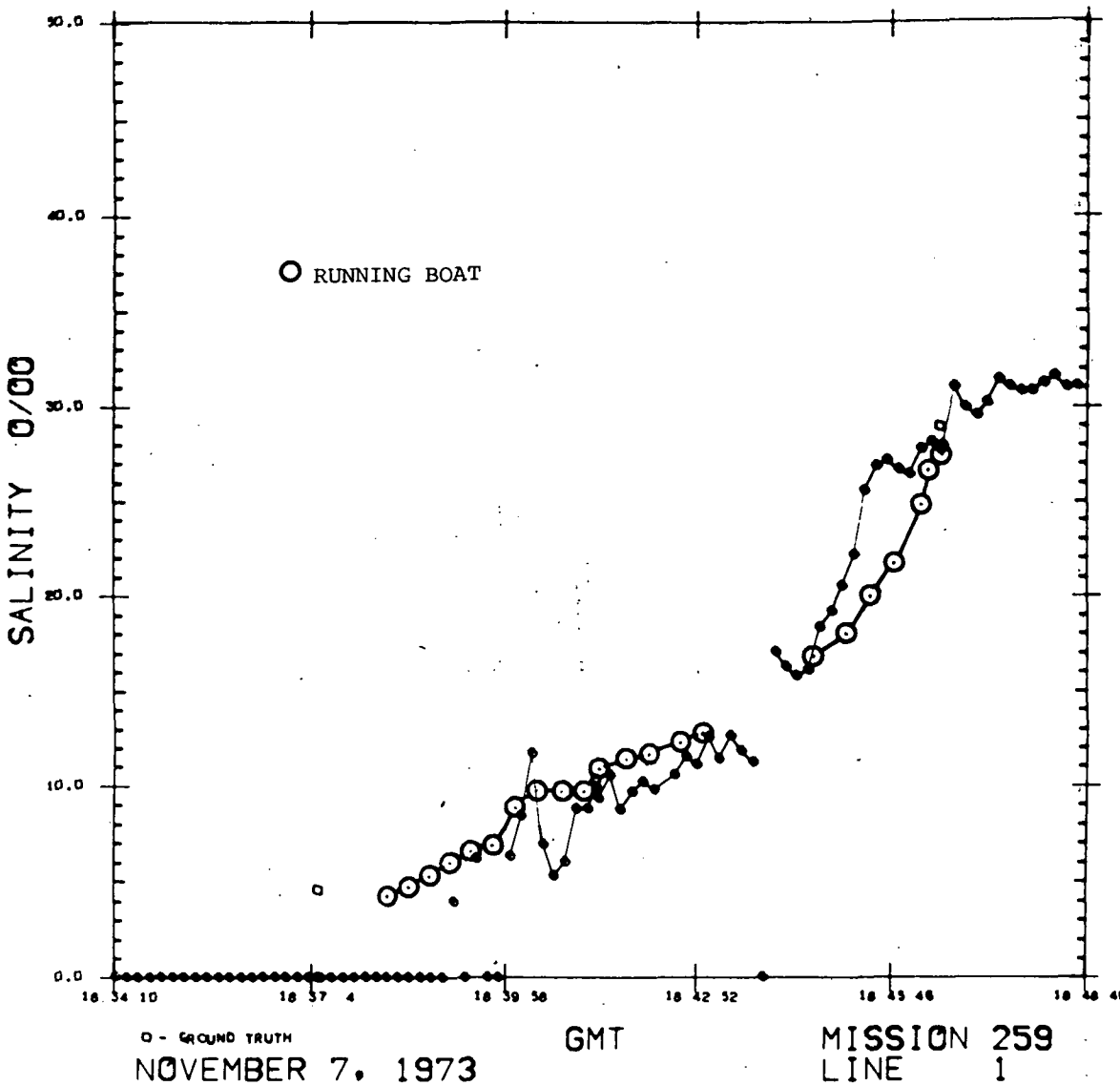


Figure 6. Remote and surface measured salinity values for run 4 of the November 7, 1973 experiment.

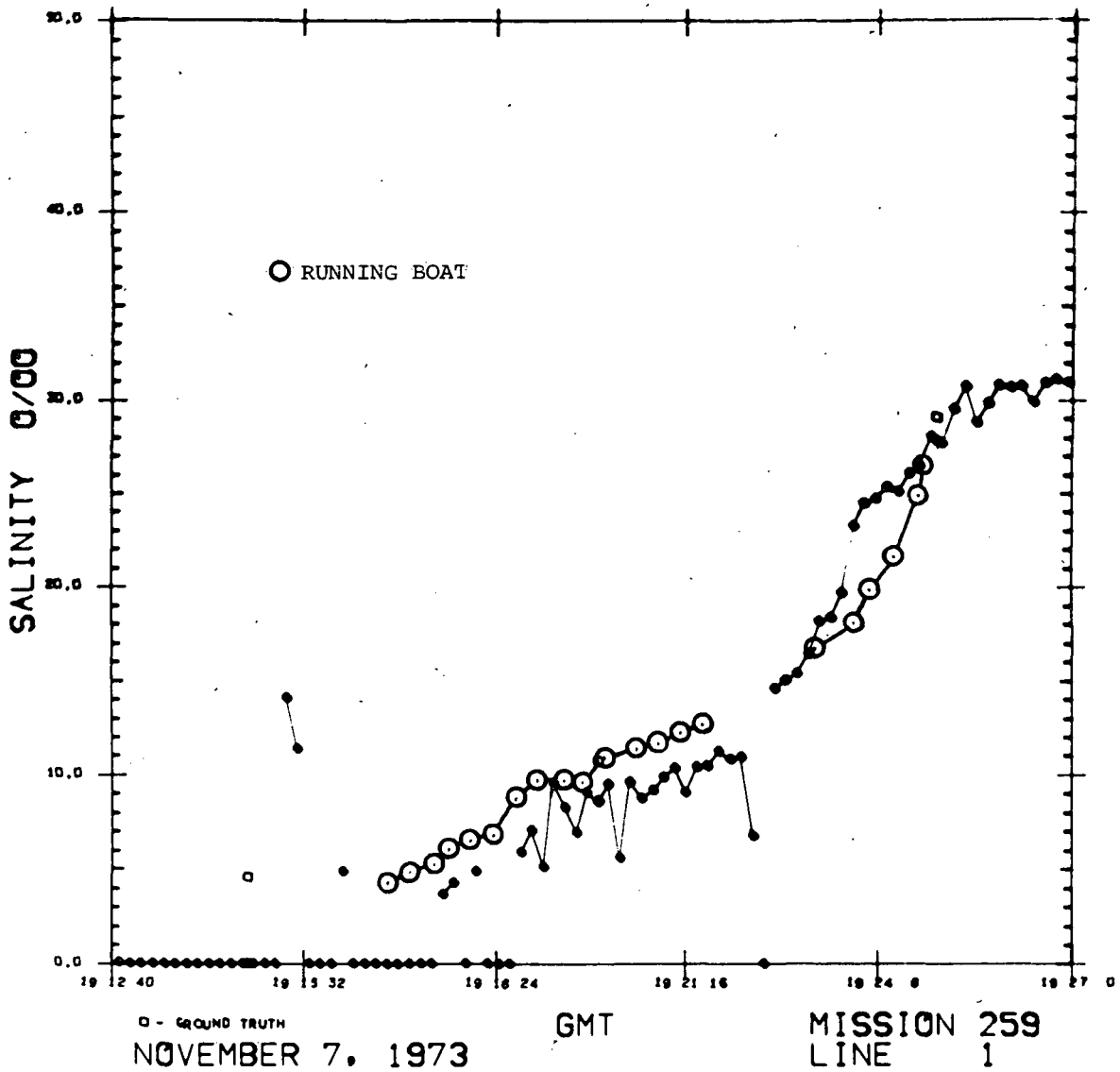


Figure 7. Remote and surface measured salinity values for run 6 of the November 7, 1973 experiment.

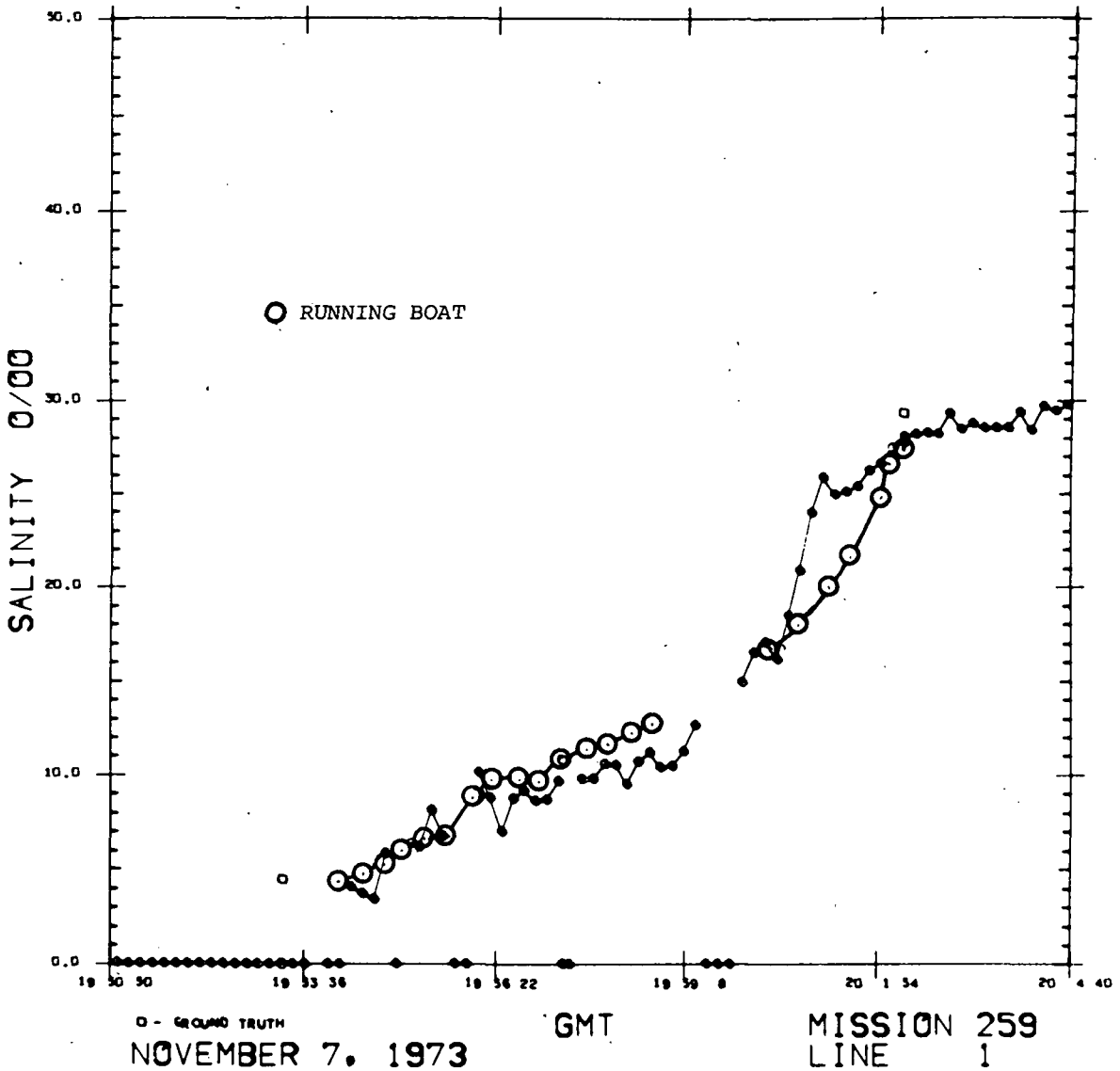


Figure 8. Remote and surface measured salinity values for run 8 of the November 7, 1973 experiment.

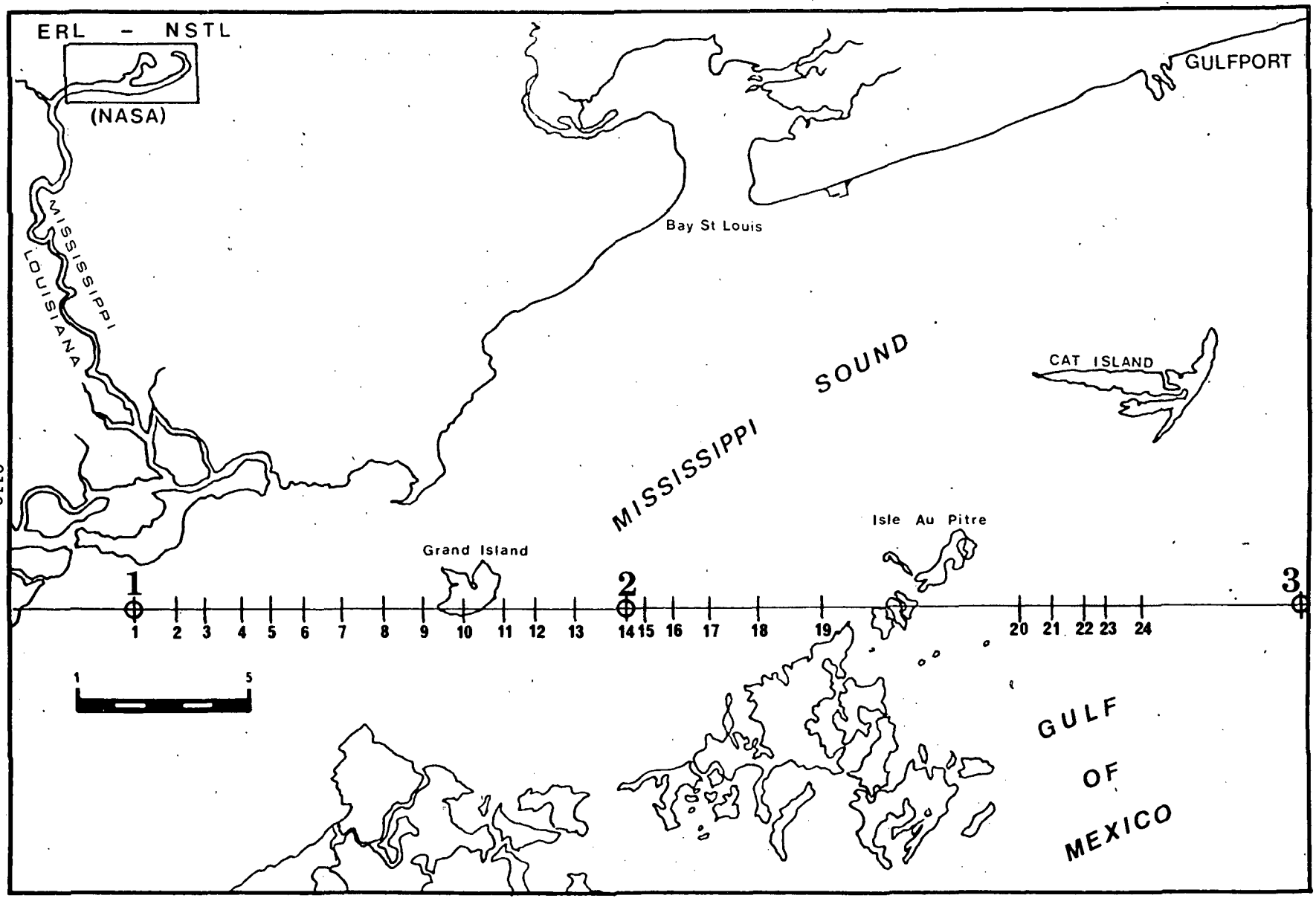


Figure 9. Flight line, stationary boat positions(circled), and moving boat measurement positions for June 4, 1974 experiment.

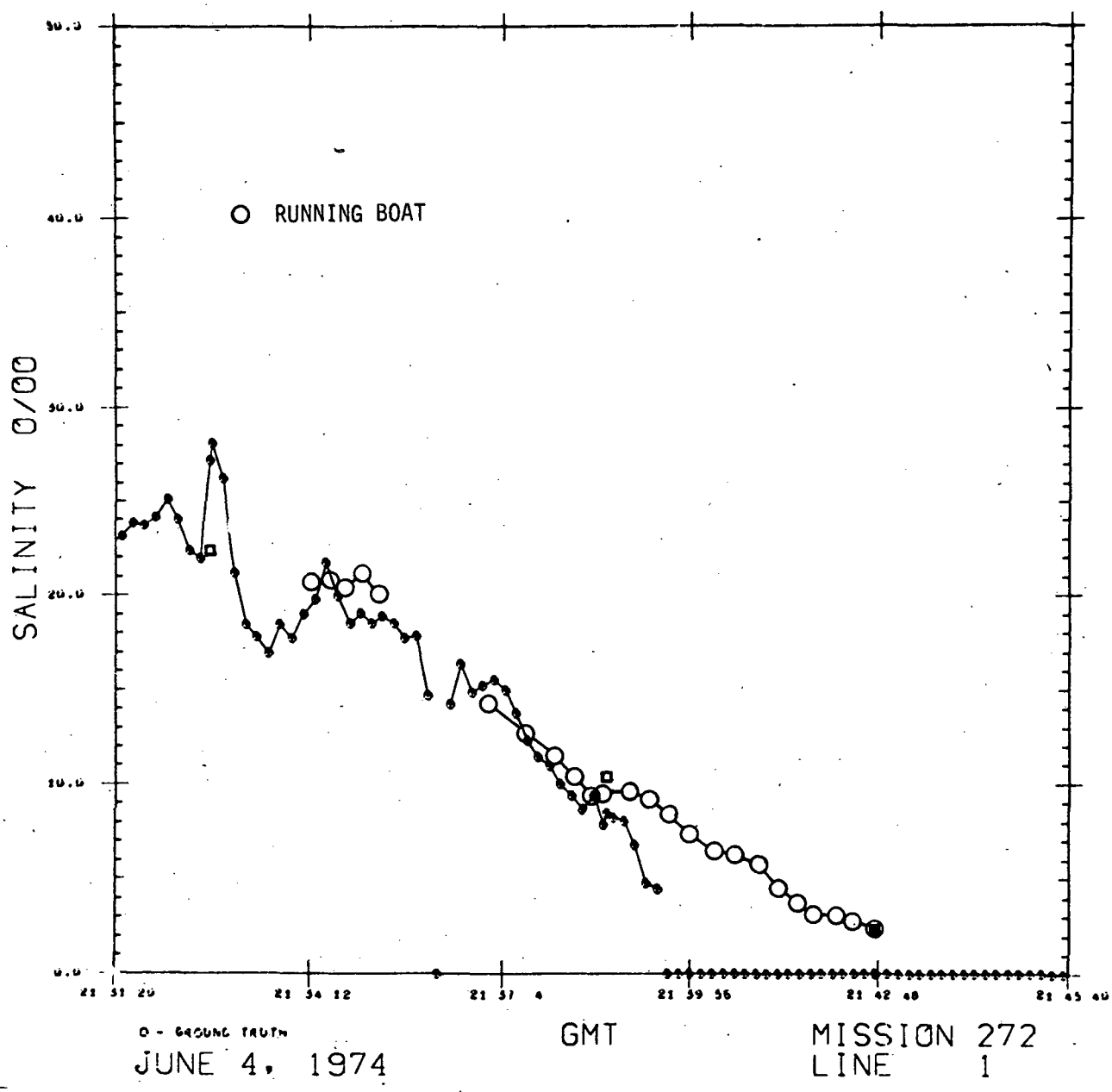


Figure 10. Remote and surface measured salinity values for run 1 of the June 4, 1974 experiment.

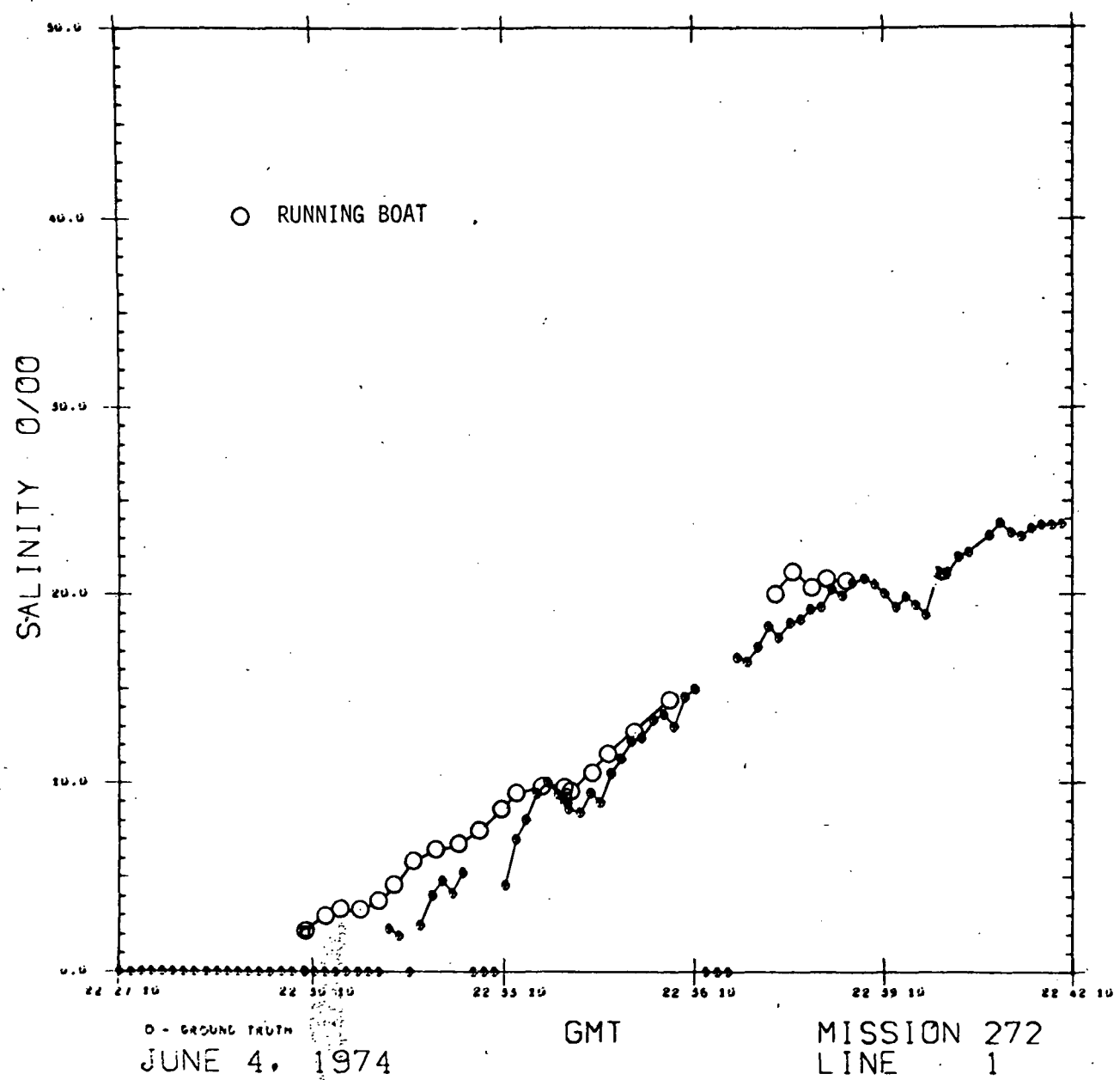


Figure 11. Remote and surface measured salinity values for run 4 of the June 4, 1974 experiment.

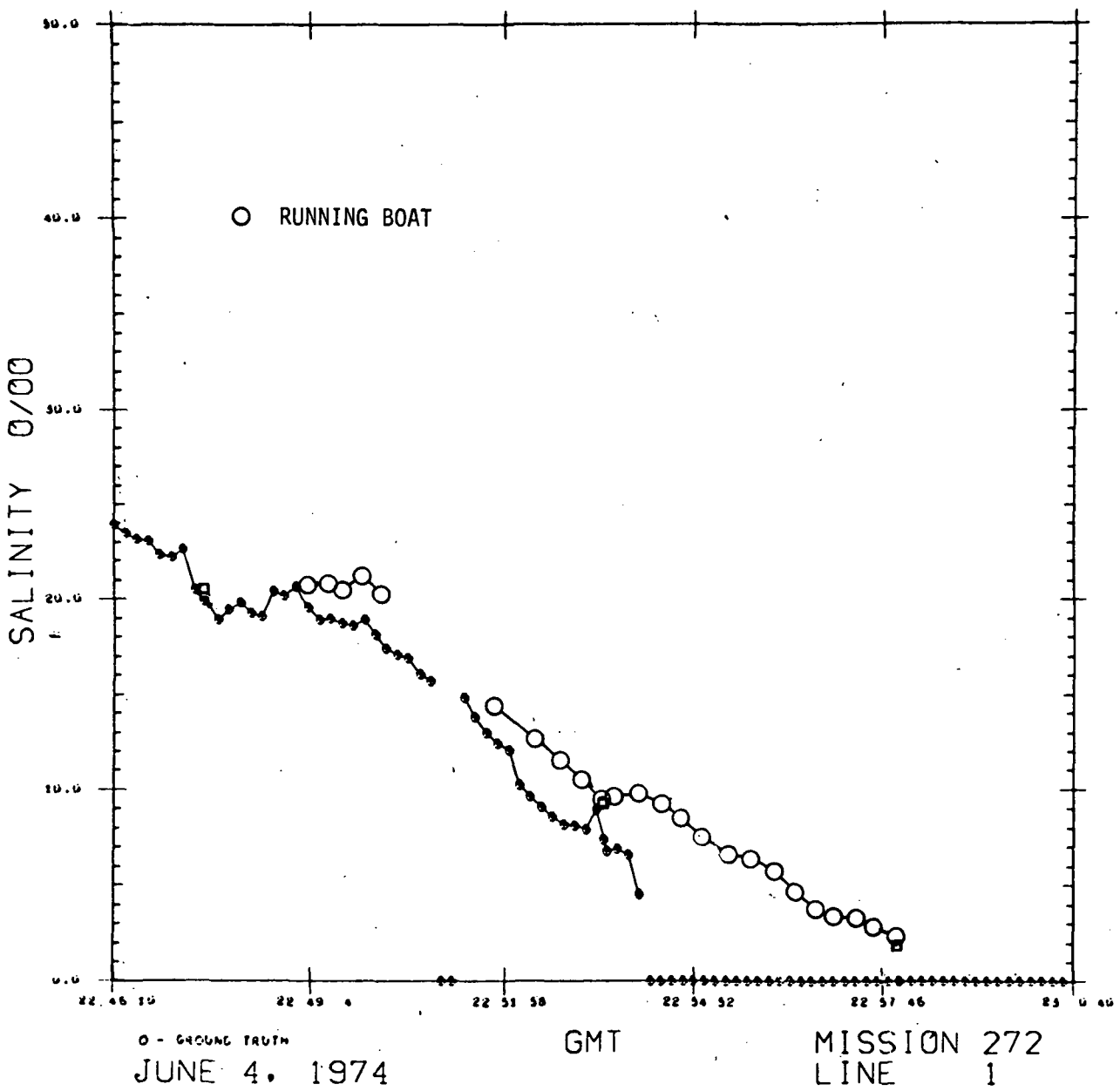


Figure 12. Remote and surface measured salinity values for run 5 of the June 4, 1974 experiment.

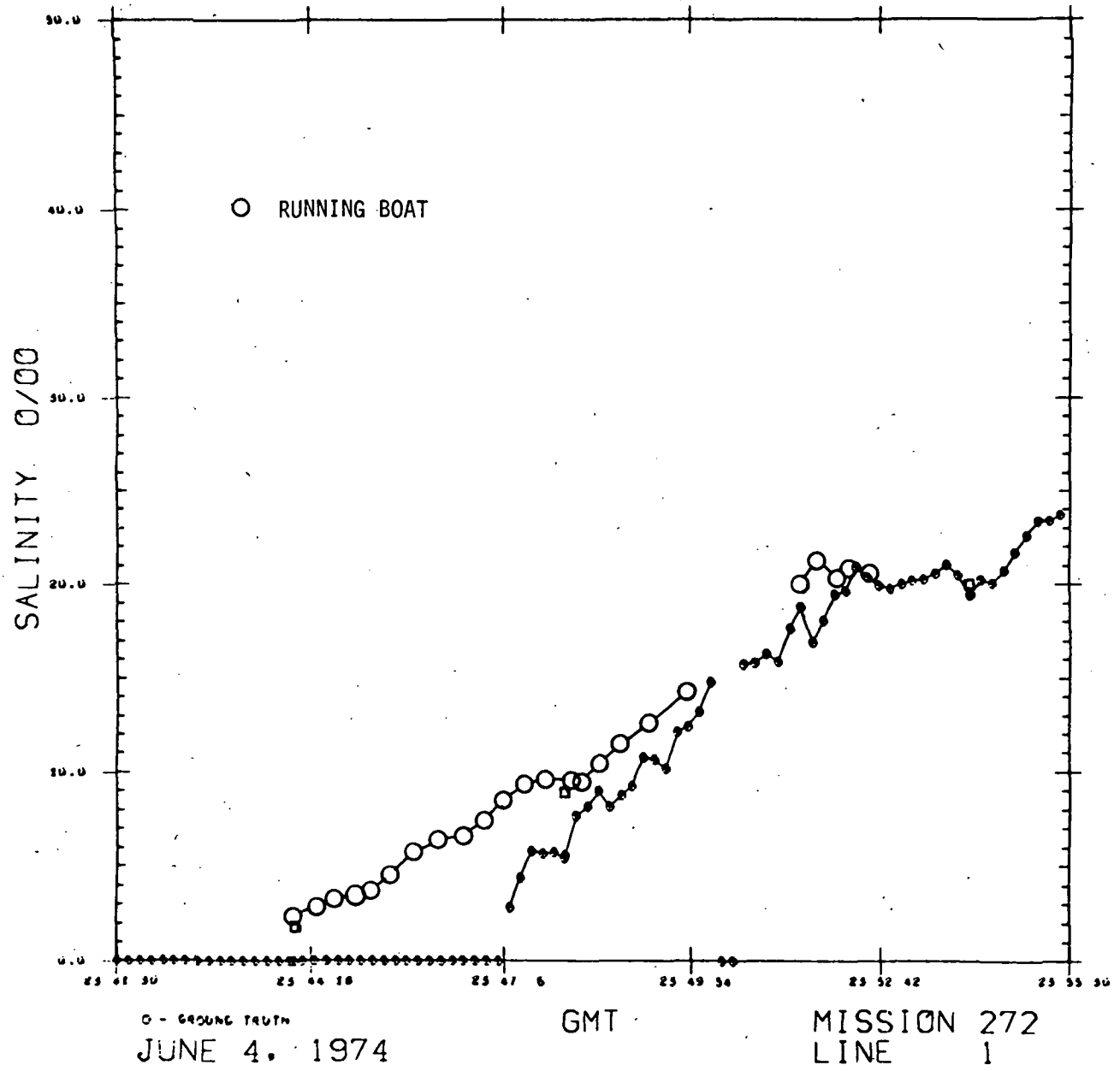
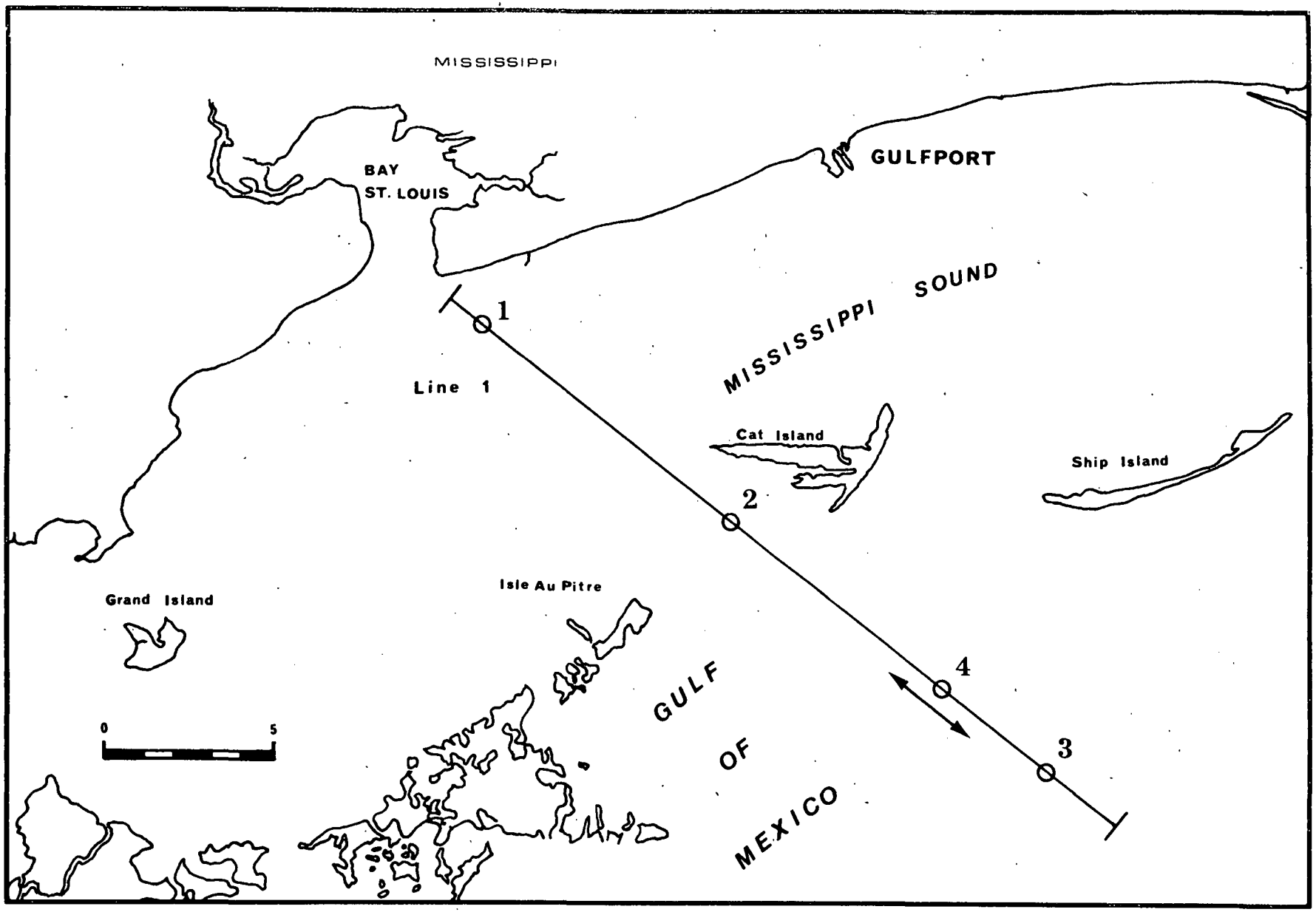


Figure 13. Remote and surface measured salinity values for run 8 of the June 4, 1974 experiment.



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Figure 14. Flight line and stationary boat positions for the April 16, 1974 helicopter experiments.

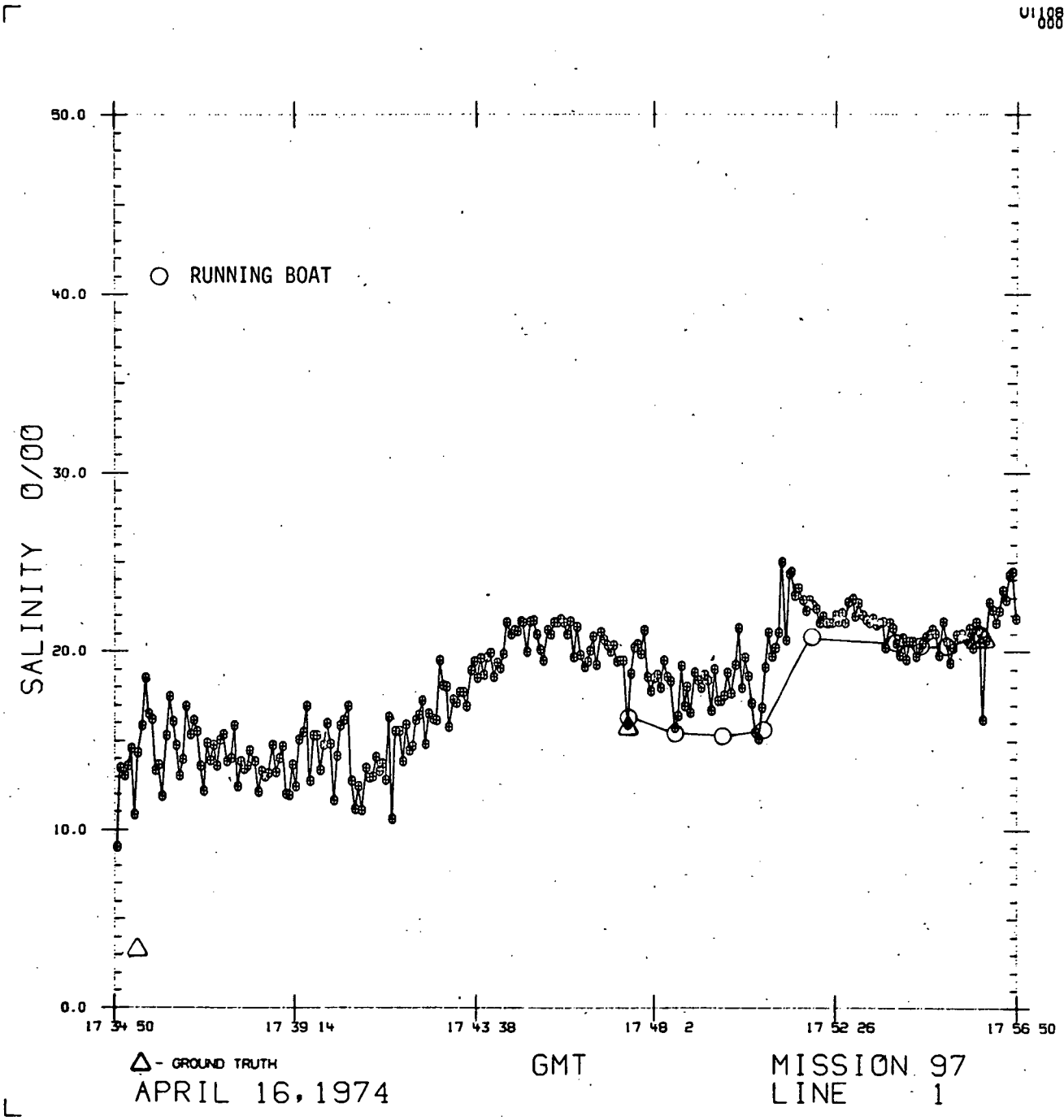


Figure 15. Remote and surface measured salinity values for run 1 of the April 16, 1974 helicopter experiment.

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0010 0000

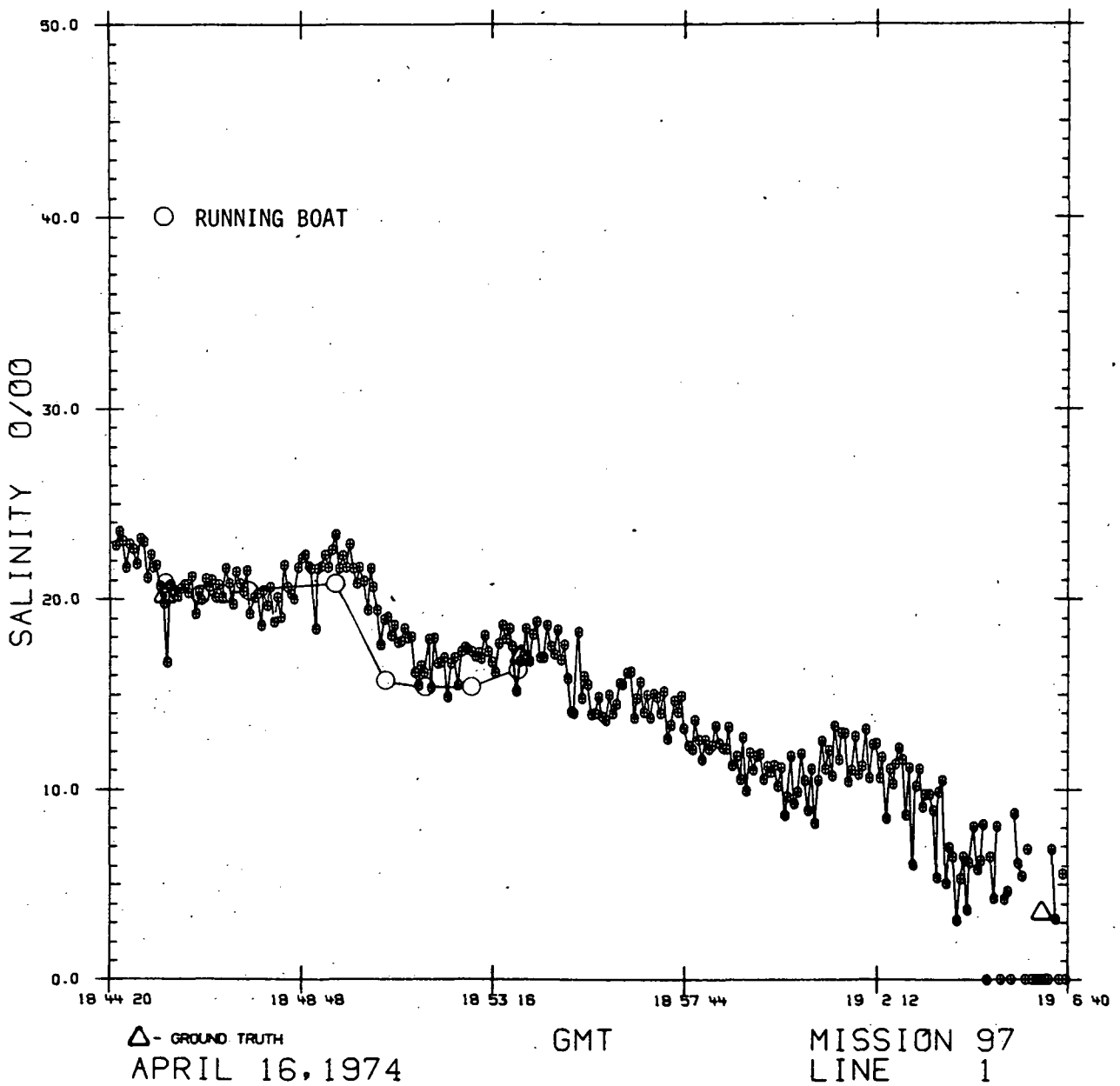


Figure 16. Remote and surface measured salinity values for run 4 of the April 16, 1974 helicopter experiment.

AUTOMATIC INTERFACE MEASUREMENT AND ANALYSIS

M-13

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ABSTRACT

A technique for detecting and measuring the interface between two categories in classified scanner data is described together with two application demonstrations. Measurements were found to be accurate to 1.5% RMS error on features of known length while comparison of measurements made using the technique on LANDSAT data to opisometer measurements on 1:24,000 scale maps shows excellent agreement. Application of the technique to two frames of LANDSAT data classified using a two channel, two class classifier resulted in a computation of 64 km annual decrease in shoreline length. The tidal shoreline of a portion of Alabama was measured using LANDSAT data. Based on the measurement of this portion, the total tidal shoreline length of Alabama is estimated to be 1313 kilometers.

INTRODUCTION

Interfaces play a very important role in the physics, chemistry, biology, sociology, and politics of the world around us. Thermal energy is transferred across the boundary between a power plant cooling water discharge and ambient water; erosion takes place at the shoreline; it is across the land/water interface in the marsh that nutrients flow, as the inorganics for primary producers and the organic materials for higher marine life; at the interface between the farmlands and the small creeks and streams fertilizers and insecticides applied to farmlands become agricultural runoff; it is at the boundary of the highway construction project with the swamp, wilderness, or tundra that the environmental impact of the highway is first felt; it is at the interface with industrial development that residential neighborhood quality frequently declines; it is at the flood plain boundary that the hazard to development suddenly changes; limits of ownership of land and mineral rights are determined by particular land/water boundaries.

Given an understanding of the mechanisms involved in the environmental dynamics, definition of the interfaces involved becomes integral to a quantitative analysis of the natural and human-induced processes. Such an analysis can provide information required for effective, properly directed management. One of the first requirements of the analysis would be to monitor the interface involved, detecting and measuring it.

Many of the boundaries we find in nature are very extensive, and are also readily detectable in remotely acquired data, making automatic analysis of aircraft or satellite data very attractive. There are numerous techniques which allow one to automatically translate remotely acquired data into readily interpretable information by classifying the data into various categories. This paper discusses a technique which allows one to delineate and measure the interface between any two such categories or groups of categories while simultaneously computing the area of each. While the technique is not restricted to the analysis of the land/water interface, it is presented here in the context of a shoreline analysis tool. It may be applied to any sampled data, but the discussion here is in terms of scanner data, such as that provided by the LANDSAT Multispectral Scanner (MSS).

In a dynamic geographical area such as a marsh or river delta, it is desirable to know what changes are taking place and to be able to estimate the rate of change. For example, the delta of the Mississippi River is, overall, losing land at a rapid rate, while land is building in the Atchafalaya River Basin. A long term study[1] indicates that the Louisiana coastal area is losing more than 16 square miles per year of land. Consequently, Gagliano, Kwon, and van Beek[2] have proposed that controlled diversions of Mississippi River flow would reduce salinity intrusion and extend the delta to reverse the trend of land loss, to increase the buffer zone for reduction of hurricane-generated storm surges, and to enhance productivity of fisheries and wildlife.

Mobile Bay is another dynamic area. Current studies[3] indicate that sediment carried into the Bay is filling the northern portion of the Bay while some areas within the Bay are experiencing land loss.

The repetitive coverage by LANDSAT provides the opportunity to observe areas experiencing land loss or gain over a period of time, under varying tide and vegetation conditions, and allows measurements of land gain or loss to be continually made and evaluated quickly. This capability is particularly important to monitor an active management plan such as that mentioned above for the Louisiana delta.

The interface between land and water is an important factor in determining marshland productivity. Using data collected in a salt marsh of southern Louisiana, Day[4] has compared streamside productivity to inland productivity (See Table I) and found that the area within 50 meters of the edge of streams, ponds, and so forth has a net productivity (in terms of grasses) approximately twice that of the inland areas. Higher marine productivity is believed to be typical of areas with highly convoluted shorelines. The length of the shoreline per unit area of water is one of the factors which might be considered in estimating shrimp production for estuary systems, but because of the difficulty of obtaining measurements of shoreline length, it has not been extensively utilized. Automatic processing of remotely acquired multispectral data makes the measurement and utilization feasible.

PROCESSING STEPS

There are ten basic elements required to derive a display showing land, water, and shoreline and a measurement of the shoreline length from multispectral scanner data, such as that obtained by the primary LANDSAT sensor. These steps are outlined in Figure 1.

The data must first be examined to determine the suitability of the data set for analysis, e.g., to verify that the entire area to be studied is completely included, that cloud cover will not interfere with the analysis, and so on. Normally, this step is accomplished by inspecting film images of the scene, while all subsequent work makes use of computer compatible magnetic tapes containing the data.

A technique for converting the LANDSAT multispectral data into a land/water thematic has been developed at Johnson Space Center and is known as the Water Search Technique.[5] It utilizes the intensity measurements in the green (0.5 - 0.6 μm) band and one of the infrared bands (0.8 - 1.1 μm). This infrared band alone provides a very good definition of land and water because water strongly absorbs radiation in that spectral region while typical land features strongly reflect this radiation. The spectral signature of water is defined as all intensity

values in the infrared band less than a particular value which is a function of the intensity in the green band. The intensity of green light reflected from the area being classified serves to adjust this value, the decision point, for varying turbidity levels of the water, a factor which can cause recognition problems in areas typified by muddy river discharges or marshes. The second step in the processing is the development of the spectral signature for water which will allow the computer to generate a land/water thematic from the multispectral data. Areas known to be land and areas known to be water are located in the data. Values of radiation intensity in the green and infrared spectral bands are then extracted for each picture element in these land and water areas. These areas are known as training samples because data from them is used to "train" the computer to recognize the two categories. A graph with axes representing the green band intensity and the infrared band intensity is developed, with data points corresponding to land features differentiated from those which correspond to water features (See Figure 2). A line is then drawn through the data which best separates the two sets of points. This line defines the land/water discriminator which will then classify each picture element in the scene being analyzed on the basis of the intensity of green and infrared light measured by the sensor.

The third step in the procedure is to examine each data point in the frame and compare the light intensity measured in the green and infrared bands to the land/water decision curve. The computer tests this data and determines whether it matches the spectral signature of water, and if it does, classifies the point as water. If it does not match, i.e., if the point falls to the right of the decision curve in Figure 2, it is classified as land. From this classification process, a new magnetic tape is generated which portrays each picture element with a code corresponding to either land or water.

After the image is classified, it is closely examined and compared to aerial photography of the area that was acquired within a reasonable time period of the scanner data acquisition. The acceptable time period is determined by the rate of change of the geography and the problems expected in the classification. Marsh areas generally are the most difficult to classify and also the most dynamic, so when marsh areas are to be classified there should be aerial photography for comparison which is not more than a year or two before or after the date of the satellite image. If the comparison shows that there are serious discrepancies between the classification and the visual interpretation of the photography, the land/water discriminator must be modified. The most common cause for such discrepancies is that the training samples are not representative of all features portrayed by the data. After modifying the discriminator, the classification process is repeated and results are compared again to the photography. These steps are repeated until a satisfactory land/water thematic has been generated.

The classification into land and water classes may be performed by any valid classification technique, and the classes do not have to be water and land per se. Instead, one of the many available classifiers may be used to generate a classification showing several types of vegetation and different types of water (e.g., lakes and rivers), or different types of ice and snow, or any other identifiable categories, provided only that the categories can be grouped into land and water superclasses. This is useful when fresh water marshes are to be analyzed, as floating vegetation which obscures the water may be grouped with the water categories for an accurate land/water discrimination. The computer program which performs the final shoreline analysis will accept as many as sixty-four classes for the land superclass and eight as the water superclass.

The data to be analyzed will frequently cover a greater area than the desired study area. For example, a typical problem is to measure the land/water interface in a coastal region using LANDSAT data, while a LANDSAT image will typically include not only the coastal area, but the inland region containing small ponds, lakes, creeks, and rivers. The region of interest must be isolated. This is accomplished by displaying the image and determining the limits of the area to be analyzed, and then changing the code for each picture element outside the area of consideration from either land or water to a third code which will be recognized by subsequent computer analysis and ignored. The image is then ready for the detection and measurement of the shoreline.

The scanner data must be scaled accurately for the shoreline measurement to be meaningful. This may be accomplished by computing the picture element size from the scanner characteristics and operating parameters together with the altitude of the platform, or from the data itself. The latter has been found to be a better approach. To determine the factors for cross track scaling (along the scan line, referred to below as the horizontal direction), and along track scaling (along the platform ground track, perpendicular to the scan direction, referred to below as vertical direction), geographic points identifiable in the scanner data are located on accurate maps. The distances between these points are measured on the maps, and the number of picture elements separating them in the scanner data along the scan line and perpendicular to it are determined. The scale factors are then computed by a least squares error analysis. In addition to the scale factors, a correction for rotation of the earth is required when the platform carrying the sensor is a satellite. This correction term is computed in the same analysis as the scale factors.

For the latitudes at which all of our work has been performed, correction for rotation of the earth beneath LANDSAT is consistently equivalent to approximately one element every eleven scan lines. However, the LANDSAT MSS scans six contiguous lines simultaneously, so that there is in fact no correction to be made within the six line units. The LANDSAT data is processed to remove the skew caused by earth rotation by shifting every twelfth scan line one picture element to the west, starting with the first scan line of a six line unit. An additional single picture element shift is introduced every 132 lines. Considering the data as a whole, the correction is therefore equivalent to one shift every eleven scan lines, and preserves the geographic integrity of the six line unit. This is particularly important for the shoreline measurement analysis, because a shift introduced between scan lines where it does not belong results in a change in the length of the linear features being measured.

With the data corrected for the rotation of the earth (if necessary) and the scale factors determined, the shoreline may be detected and measured. The grouping of classes into land and water superclasses is performed at this point, the areas of the two superclasses being computed simultaneously by counting the picture elements being placed into each one. An interface element is defined as the edge of an element of water which is adjacent to an element of land. A two picture element wide and two picture element high "window" is scanned over the classified image, and each element of shoreline is noted. There are four basic types of interface elements: horizontal (i.e., two water elements in one scan line, two land in the other); vertical (e.g., the first element of each scan line within the window is land and the second is water); diagonal (see Figure 3a); and corner (see Figure 3b). Each of these types has a different length, so the number of each type of interface element is accumulated for the entire image. After scanning the entire image, the number of each type of interface element is multiplied by its respective length and these products are then summed to give the total interface length.

The scale factor analysis determines the length of each interface element type. The horizontal and vertical elements contribute one picture element width and height, respectively. The diagonal contribution is the square root of the sum of the squares of the width and height, and corresponds exactly to the diagonal measure of the picture element. Because sharp corners are not typical of natural scenes, the contribution of such apparent features is that of a rounded corner, the length being one-half the width plus one-half the height of the picture element, plus one-quarter of the average of the perimeters of the ellipses which can be inscribed and circumscribed on the picture element.

The final step in the processing, which is performed simultaneously with the interface detection and measurement, is the generation of a new image of the scene being analyzed. This image is a modification of the isolated land/water image which shows the interface as a fourth category, in addition to the land, water, and excluded area. This is accomplished by changing the code on the magnetic tape for every picture element of water which was found to be adjacent to an element of land. This final image is normally recorded on film, examples of which may be seen in Figures 4 and 5.

EVALUATION OF MEASUREMENTS

The interface measurement technique was first tested on figures constructed of string of known length. Various shapes were studied, with figures at different orientations to the sampling grid which was applied to simulate scanner data. Different size grids were also employed. In order to provide a meaningful evaluation, the string figures were of such complexity that all major figure details could be resolved in the sampled data. This study showed that the measurement was very accurate, giving a root mean square error of 1.5% for the figures analyzed. There was also little sensitivity to rotation of the sampling grid.

The technique was then applied to a group of geographic features which could be clearly defined in LANDSAT imagery. These consisted of islands, lakes, and canals which were also accurately portrayed on USGS maps. The shoreline analysis technique was applied to the LANDSAT data while the features were measured on 1:250,000 and 1:24,000 scale maps using an opisometer. Table II presents the results of the analysis. The comparison with the small scale map at first appears disconcerting until the opisometer measurements on the two different scale maps are themselves compared. The LANDSAT-based measurements compare very favorably with the large scale map measurements, with a root mean square deviation of only 7%. Because the interface lengths as computed from the satellite data exceeded the small scale map measurements consistently, and this excess was reduced when the large scale maps were used, it appears that the LANDSAT data contains more detailed information about the features analyzed than the small scale maps, either because of greater fidelity in the detail or higher spatial resolution. Alternatively, the deficiency in the map analysis could be in the opisometry. However, the good agreement indicates that the interface measurement technique may be applied to LANDSAT data with results that will be comparable to measurements made on 1:24,000 scale maps by traditional methods.

One feature which was analyzed but not included in the evaluation deserves special mention. A bridge which crosses Lake Pontchartrain, Louisiana, is 38.41 kilometers long. It was identified in a LANDSAT image which was analyzed using Water Search to define the bridge, which was then isolated from the adjoining

lakeshore. Application of the interface detection and measurement technique resulted in a calculated length in error by approximately 55 meters--a deviation less than 0.2%.

The problem of resolution deserves further attention. An area of the marsh in Louisiana near Grand Isle has been analyzed using data with two different resolutions: LANDSAT data, with 79 meter resolution, and aircraft scanner data, with a resolution of approximately 4 meters. The two analyses did not cover exactly the same area, with the LANDSAT data extending slightly beyond the coverage of the aircraft data. However, the aircraft data indicated a shoreline length 54% greater than that measured in the satellite data. Carried to its extreme, resolution may be increased to the point at which the perimeter of every blade of grass is being included in the measurement, at which point the measurement becomes of little practical value. It is clear, however, that the resolution of the data upon which the interface analysis is performed must be associated with the resulting measurement. This is also true with traditional methods, as increasing map detail yields increasing shoreline length.

APPLICATION DEMONSTRATIONS

Two projects demonstrating the application of the automatic shoreline measurement technique have been completed. The first was an analysis of the Mississippi River delta and was designed to detect changes between two frames of LANDSAT data acquired approximately one year apart; the second was to measure the shoreline of Alabama.

Mississippi River Delta Study.- The Mississippi River delta is an area of particularly rapid change, with a very rapid rate of land loss. According to one study[2] the 50% land/water isopleth retreated over 16 kilometers in that region between 1930 and 1970 and is projected to retreat an additional 50 kilometers by 2000.

The Garden Island Bay subdelta is a typical area. In 1935, several small ponds and minor distributaries broke up what was otherwise continuous land (see Figure 6a). By 1958 (Figure 6b), the ponds had expanded considerably, resulting in a substantial loss of land area. At the same time, however, it appears that the length of shoreline in the subdelta increased.

The satellite data indicates that the trend of land loss is continuing both in the Garden Island Bay subdelta and the lower delta in general. An area was isolated downriver from Boothville, Louisiana in two frames of LANDSAT data, acquired on January 16, 1973 and December 5, 1973. The data was processed using the Water Search Classifier and the Interface Detection and Measurement computer program. The January data gave a land area measurement of 428 square kilometers and a shoreline length of 4039 kilometers. Comparison of the classified data to the quadrangle maps showed that the trend of land loss was continuing in the Garden Island Bay subdelta while land building was continuing along Pass a Loutre.

The second frame (December 5, 1973) was processed identically. Scale factors and parameters in the classification were different because of different altitude of the satellite, different lighting conditions, and change in the calibration of the sensor. The analysis indicated that the land area was then 411 square kilometers and the shoreline length was 3980 kilometers. A decrease of 58 kilometers in shoreline length and 17 square kilometers is therefore indicated by the analysis. There are several striking examples of land loss: in the vicinity of Grande Pass, near Baptiste Collette Bayou, and at the mouth of Main Pass (circled areas 1, 2,

and 3 in Figure 4). However, land has built up between Main Pass and Baptiste Collette Bayou.

This change detected must be considered in its proper context. The two measurements represent two instants in time, and do not in any way represent mean conditions. Two significant variables which were not controlled were tide stage and vegetation growth. One point where tide stage difference is evident is the island in the mouth of Main Pass. According to the navigation charts (C&GS 1272, dated 1972) the island appears as depicted in the December frame. However, a mud flat is indicated surrounding the island, the boundary of which corresponds to the shape of the island as it appears in the January frame. Accurate and meaningful stage data is not available; there are, however, indications that the tide was in fact slightly lower for the January satellite pass, which would explain some of the decrease in exposed land for the December frame.

The vegetation problem is more subtle. Floating vegetation and vegetation growing in the intertidal regions causes areas that should be classified as water to be recognized as land, because the water surface is hidden by the vegetation. The problem is minimized in this case because the data was taken in the winter months when the plants had died back to their minimum extent. A non-seasonal change in the plant life did take place during that eleven-month period. The vigor of vegetation along the west bank of the river to Southwest Pass seems to have been reduced considerably from the appearance of the area in satellite and aircraft imagery. The change in vegetation state began during the eleven month interval and is continuing. Why this has taken place is not known, but the effect on the land/water consistency of the area is significant. Much of the land loss detected took place in this area of altered vegetation state.

Another measurement of approximately the same area has been made by the Coastal Resources Unit of the Center for Wetland Resources at Louisiana State University.[6] The measurements of streams and bayous, canals and dredge cuts, and major rivers were made using an opisometer on the quadrangle maps which were available for the area while a tracing technique was used to determine the length of lake, bay, and marsh shorelines. This tracing technique involved drawing an ink line over the shoreline shown on the quadrangle map and detecting the change in weight of the sheet as a result of this inking. The ink weight was then calibrated to line length. This technique was found to have what Becker calls good "agreement between replications" on repetitive measurements, and agreement within 20% of true values. The shoreline lengths are listed by both quadrangle sheet and what is referred to as hydrologic unit. The quadrangle maps which cover slightly more than the area included in the LANDSAT study yielded a shoreline length of 5483 kilometers by Becker's composite technique. Hydrologic Unit II of the Becker Study corresponds closely to the slightly larger area included in the LANDSAT study and was determined to have a shoreline length of 4796 kilometers. If this value corresponds to the measurement made in the satellite analysis, a decrease of 54 kilometers of shoreline per year has been occurring since the 1958-1960 date of the quadrangle maps. Considering the fact that short term and periodic effects are included in the change measured in the satellite study, the 64 kilometer loss per year computed in that study is not unreasonable.

Alabama Shoreline Study.- The measurement of the shoreline of Alabama was undertaken at the suggestion of the Remote Sensing Section of the Geological Survey of Alabama. Previously published values of the shoreline length for the state varied from the U.S. Army Corps of Engineers' measurement of 491 kilometers to a

NOAA measurement of 977 kilometers. The Geological Survey of Alabama, in what they considered to be a conservative estimate, determined the land/water interface length in the tidal region to be 811.3 kilometers, using 1:24,000 and 1:62,500 scale maps.

As in the case of the Mississippi River Delta study, two frames of LANDSAT data were analyzed. The entire coastal region of Alabama was not included because of the limited resources allocated to this project, with the area of consideration being restricted to the region bounded on the west by the Alabama-Mississippi state line and on the east by longitude 87° 42'W. This excludes the Perdido Bay area and requires only two computer compatible tapes for each date.

Data from December 28, 1972 and from December 5, 1973 were analyzed. Winter dates were chosen again to minimize the effects of vegetation. Aerial photography acquired in February 1973 (NASA Earth Resources Aircraft Project, Flight Number 73-023) was compared with the computer land/water category classification. There was some difficulty in detecting the narrow water courses in the marsh areas north and west of Mobile Bay, which demonstrates the effect of sensor resolution on the portrayal of the scene. The detection of small streams was more complete in the 1972 data and may be the result of any of a number of factors including atmospheric conditions, vegetation state, and sensor performance. It is also likely that the streams were swollen at the time the 1972 data were collected. Discharge data for the Mobile River indicated a flow approximately one-third greater in December of 1972 than in December 1973. While the drainage areas for some of the streams in question are different from the Mobile River Basin, the Mobile River conditions were representative of the entire area. Differences in the final shoreline measurement are due primarily to the ability to resolve the small streams and marsh land/water features. This is seen in figures 5 and 7, the shoreline images from the analysis.

The 1972 data yielded a land/water interface length in coastal area studied equal to 1122 kilometers, while the 1973 imagery was found to have a shoreline length of 879 kilometers. The latter measurement is comparable to the 977 kilometer measurement published by NOAA, although the area included in the satellite study is somewhat smaller. It represents a measurement under what might be considered normal conditions, while the higher value is the shoreline length during a flood. The Geological Survey extrapolated the LANDSAT-based shoreline measurement to include the entire coastal area of the state (adding the Perdido Bay region) and estimated that the mean shoreline length was 1313 kilometers, considerably more than both the NOAA and Survey estimates.

CONCLUSIONS

A technique for the automatic extraction of interface length from remotely acquired data has been developed. While designed for use with scanner data, any form of sampled data may be used. The technique for measuring the interface is very accurate, but the overall accuracy of the remote measurement system must be compared to a surface truth standard. The closest thing available to a surface truth standard is the USGS quadrangle maps, although these have admitted shortcomings, not the least of which is the fact that they tend to be out of date. The classification of the scanner data and geometric distortion are factors in the automatic analysis which contribute to error. Even considering these, the agreement with map-based measurements is very good.

Two demonstration projects were undertaken to apply the technique to actual problems. The active delta of the Mississippi River was studied using LANDSAT data

acquired at an interval of nearly a year. The land area and shoreline length were both found to decrease during that period at annual rates of 18.5 km^2 and 64 km, respectively. Two frames of LANDSAT data covering most of coastal Alabama were analyzed. One represented normal conditions while the other was acquired during a period of flooding. The Geological Survey of Alabama has accepted this data and extrapolated it to cover the remaining portion of the coastal area to give a tidal shoreline length for the state 34% greater than the largest previous estimate. While the LANDSAT analysis is still being evaluated, it appears to be the most accurate.

ACKNOWLEDGMENTS

The original suggestion to develop a technique for automatically detecting and measuring shoreline was made by Dr. G. C. Thomann of the Earth Resources Laboratory. The algorithm for carrying out this task was implemented on the computer by J. G. Glydewell of Lockheed Electronics. Glydewell was also responsible for performing the computer work necessary for the geometric corrections and analyses upon which the evaluation of the technique is based. His dedication to the work is greatly appreciated, as well as the efforts of Marjorie Smith and Helen Isbell in typing this paper.

REFERENCES

1. Gagliano, S.M., and J.L. van Beek, 1970. Geologic and Geomorphic Aspects of Deltaic Processes, Mississippi Delta System. In (S.M. Gagliano, R. Muller, P. Light, and M. Al-Awady) Hydrologic and Geologic Studies of Coastal Louisiana, La. State University, Coastal Studies Institute and Dept. of Marine Science. Vol. 1, 140 pp.

2. Gagliano, S.M., H. J. Kwon, and J. L. van Beek, 1970. Hydrologic and Geologic Studies of Coastal Louisiana, Report No. 9, Deterioration and Restoration of Coastal Wetlands. Coastal Engineering, Proceedings of the 12th Coastal Engineering Conference, Sept. 13-18, 1970. Vol. 3, Ch. 107, pp. 1767-1781.

3. Emplaincourt, J.L.G., and C.C. Wielchowsky, 1974. Detection of Shoreline Changes from ERTS-1 Data. Southeastern Geographer, Vol. XIV, No. 1, pp. 38-45.

4. Day, J.W., Jr., W.G. Smith, P.R. Wagner, W.C. Stowe, 1973. Community Structure and Carbon Budget of a Salt Marsh and Shallow Bay Estuarine System in Louisiana. Publication No. LSU-SG-72-04, LA State University, 77 pp.

5. Johnson Space Center, 1973. Procedure Manual for Detection and Location of Surface Water Using ERTS-1 Multispectral Scanner Data, JSC, Houston, Tx.

6. Becker, R.E. , 1972. Hydrologic and Geologic Studies of Coastal Louisiana, Report No. 15, Measurement of Coastal Louisiana's Shoreline. Prepared for Dept. of the Army, New Orleans District Corps of Engineers, Contract No. DACW 29-70-C-0272. 16 pp.

TABLE I

PRIMARY PRODUCTION IN THE BARATARIA BAY AREA [1]
OF LOUISIANA IN g DRY WT/M^2/ YEAR

MARSH		PRODUCTION GROSS	NET*
GRASS:	STREAMSIDE	14000	2960
	INLAND (50m)	9750	1484
	AVERAGE OVER MARSH	8418**	1518**
EPIPHYTES:	STREAMSIDE	103.9	60
	INLAND (2 m)	27.3	- 18.4▲
	AVERAGE (to 2 m)	32.2	25.8▲
WATER			
PHYTOPLANKTON		598	418
BENTHOS		698	488

* Net production is less respiration of plants
** Takes into consideration bare areas on marsh
▲ Community net production for epiphytes

[1] Day, John W., Jr; Smith, William G; Wagner, Paul R; Stowe, Wilmer C: Community Structure and Carbon Budget of a Salt Marsh and Shallow Bay Estuarine System in Louisiana, LSU-SG-72-04, Louisiana State Univ., 1973, p 13.

TABLE II

AUTOMATIC SHORELINE MEASUREMENT EVALUATION
USING LANDSAT DATA

TEST AREA	COMPUTER MEASUREMENT (km)	PER CENT DEVIATION OF MAP MEASUREMENT *	
		1:250,000	1:24,000
1. Gulfport to Broadwater	12.57	4.1	4.5
2. Deer Island	15.62	3.3	5.4
3. Big Creek Lake	58.48	35.6	-7.4
4. Petit Bois Island	18.48	12.7	*
5. Dauphin Island	79.89	15.7	2.9
6. Inner Harbor Navigation Canal	13.13	*	12.3
7. Anchor Lake	4.79	-0.8	*
8. Pass Christian to Gulfport	23.54	21.8	*
9. Long Beach to Gulfport	5.45	27.7	0.7
10. Grand Island	12.68	36.9	3.6
11. Calumet Island	5.79	18.8	-10.9
12. Island north of Grand Isle	4.12	4.8	*
Root Mean Square Deviation		20.6	7.0

*Excluded because of discrepancy between the appearance of the feature on the map and in the LANDSAT image.

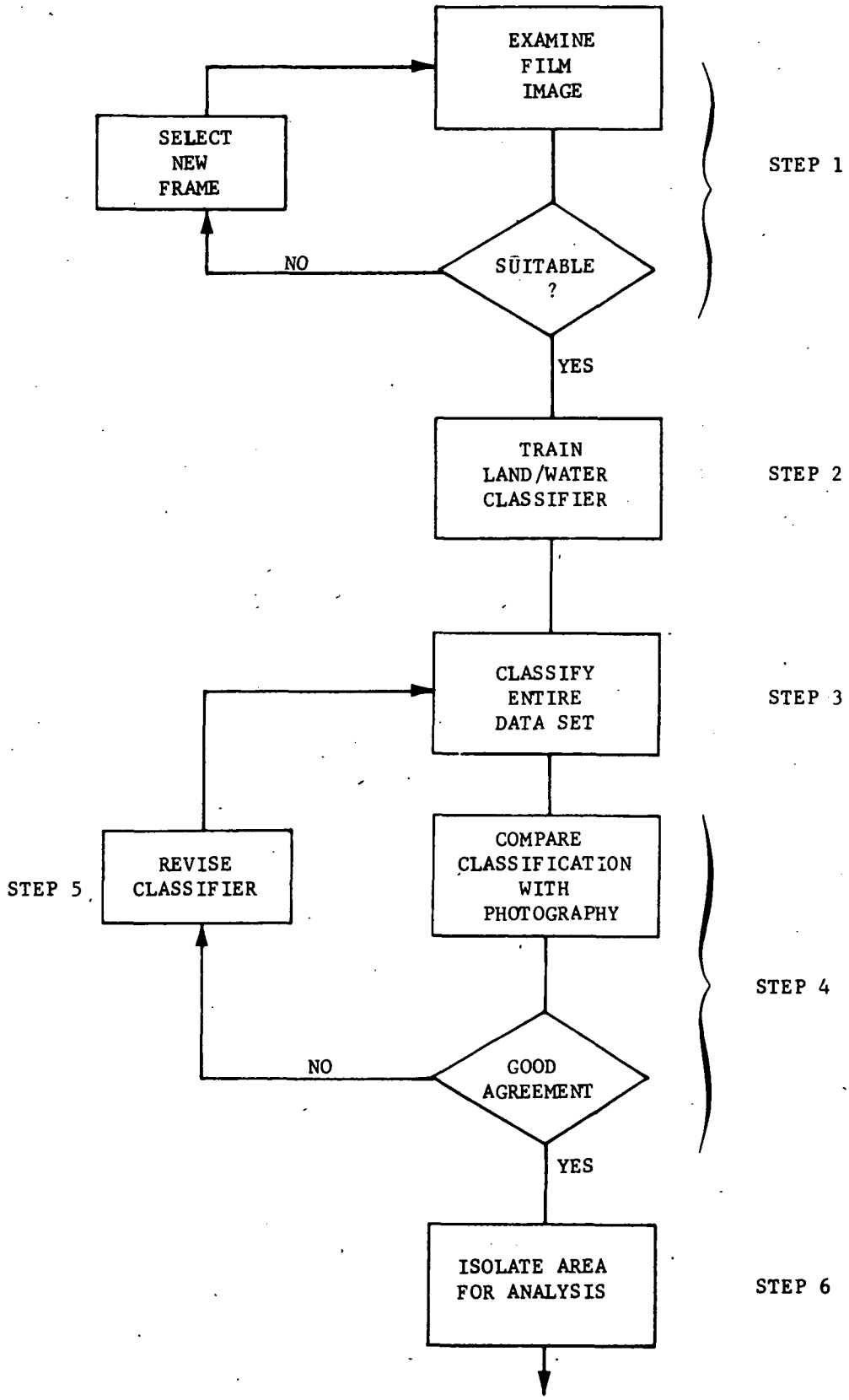


Figure 1. Processing steps to translate multispectral scanner data into land/water/shoreline image and measure shoreline length.

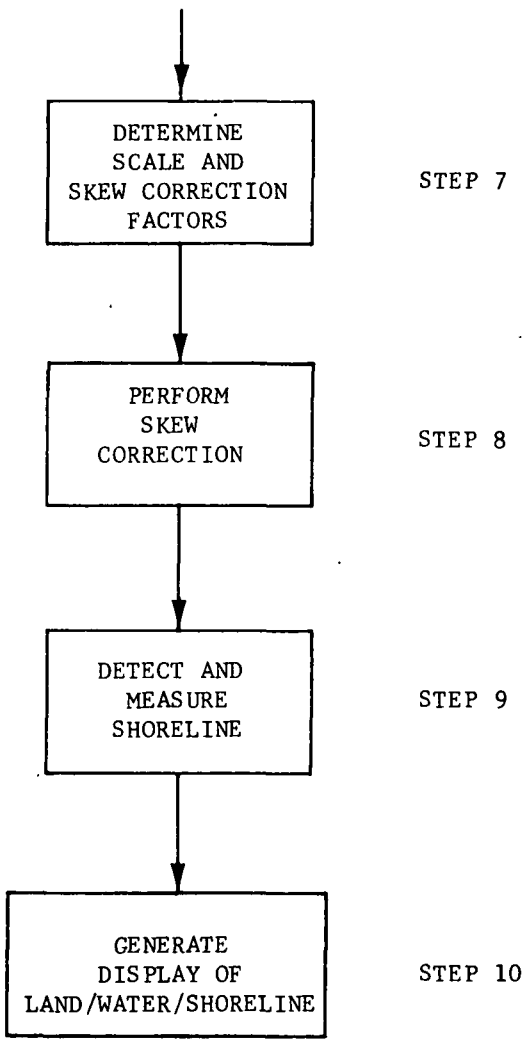


Figure 1. (continued).

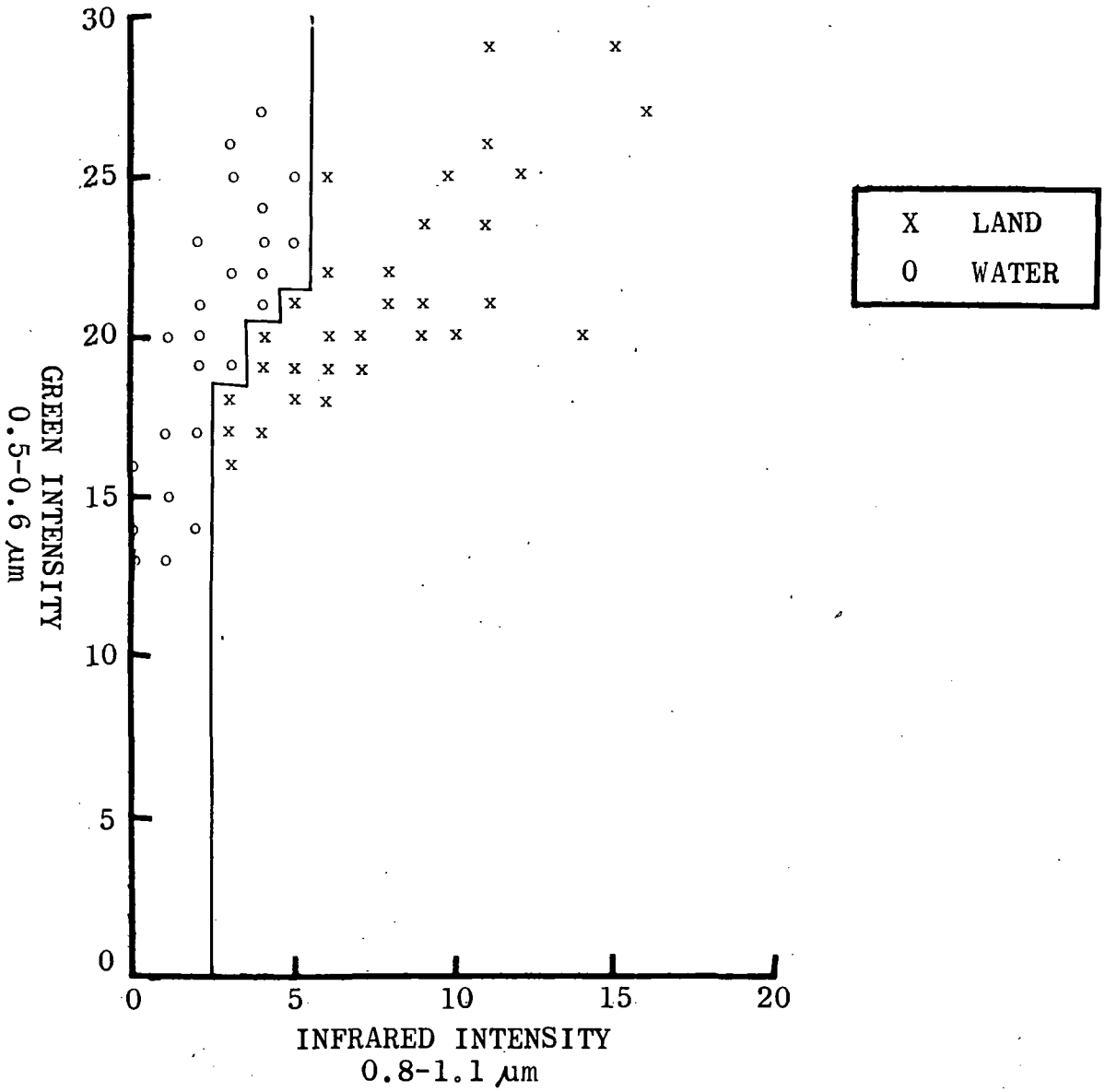
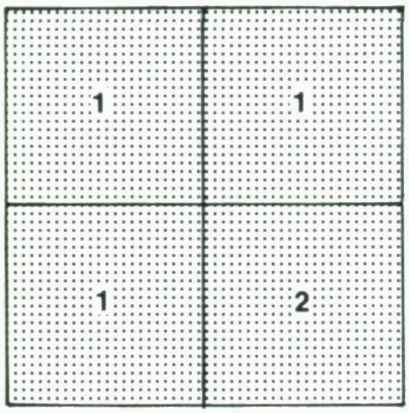
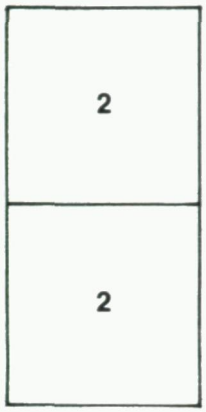


Figure 2. Development of decision curve for LANDSAT MSS Land/Water discriminator.





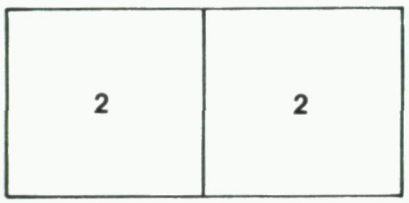
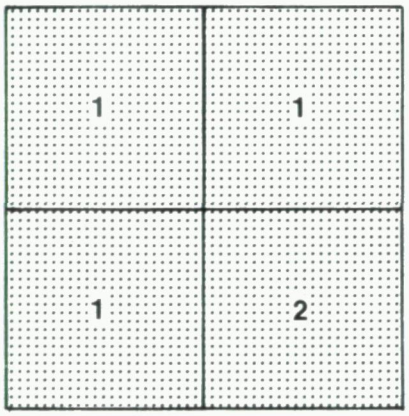


Figure 3a.
One configuration of land (class 1) and water (class 2) indicating a diagonal interface feature.



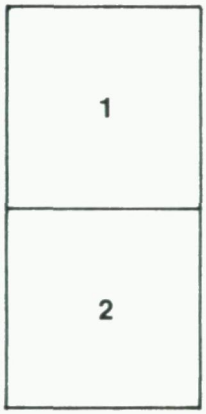




Figure 3b.
One configuration of land and water indicating a corner interface feature.

LAND / WATER INTERFACE ANALYSIS

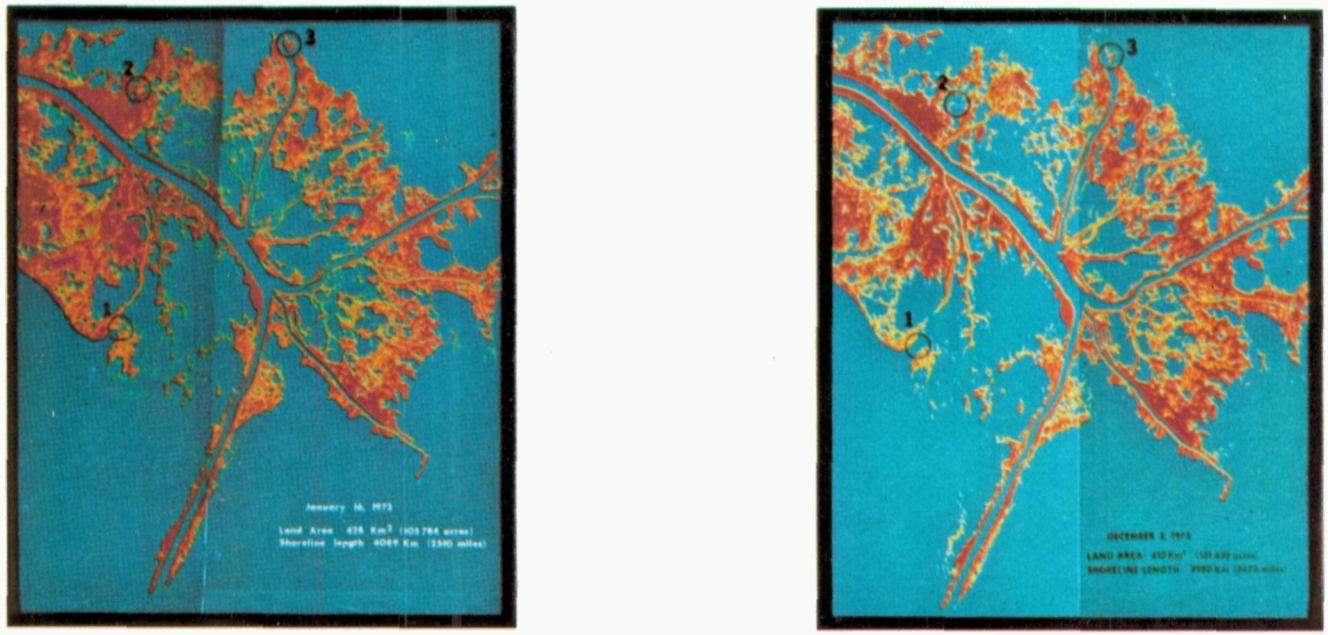


Figure 4.- LANDSAT MSS data, processed by water search and shoreline analysis programs, indicates a 17 km^2 land area decrease and 58 km loss of shoreline at mouth of Mississippi River, between January and December of 1973.



Figure 5. Tidal shoreline measurement using LANDSAT data from 1972 was 1122 km.

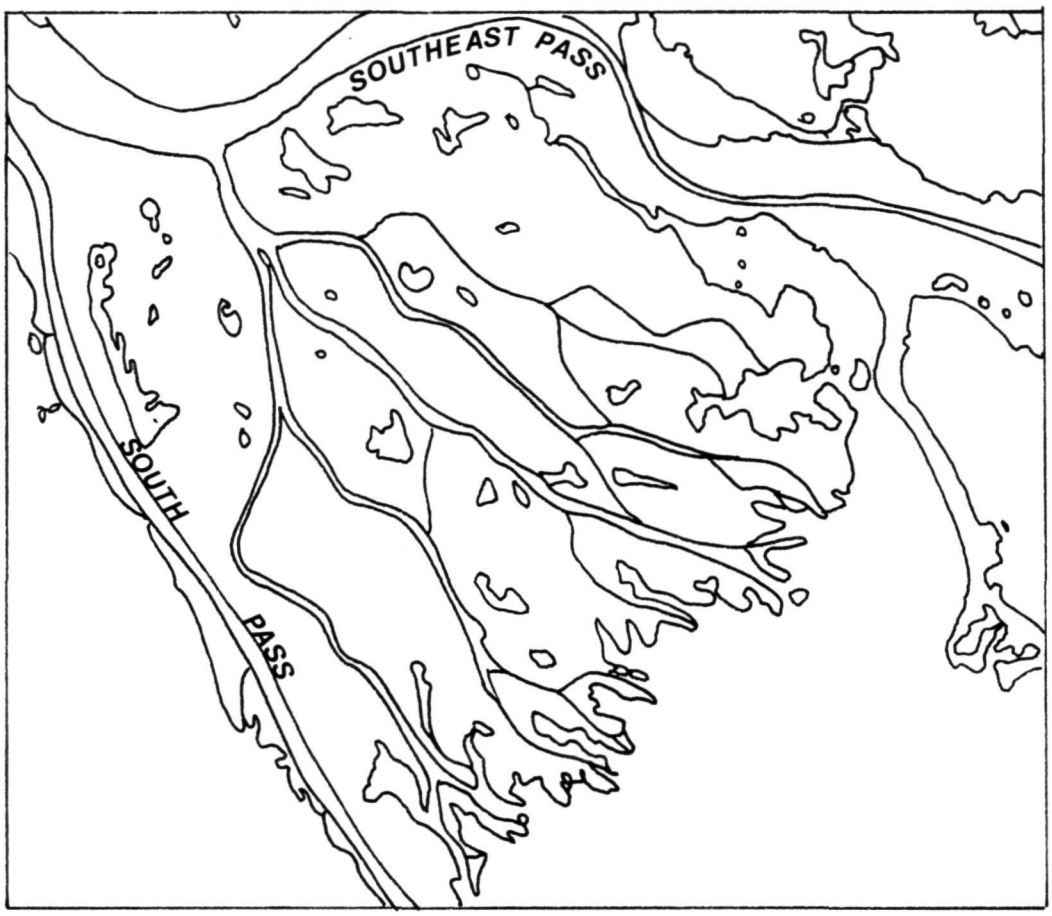


Figure 6a. Garden Island Bay Subdelta of Mississippi River in 1935. Land is broken by a few small ponds and the distributaries.

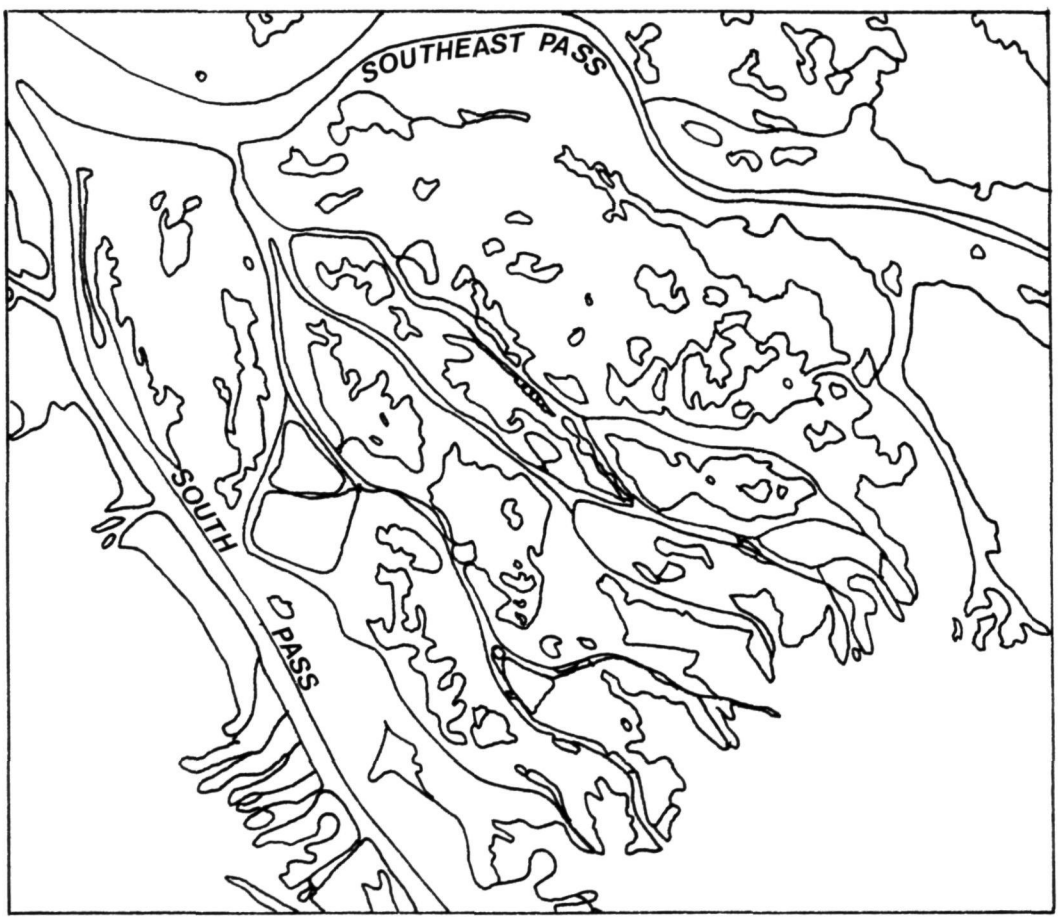


Figure 6b. Garden Island Bay Subdelta in 1958. Land area in subdelta has decreased as a result of subsidence and coastal erosion. Land building is apparent on the west side of the southwest pass.

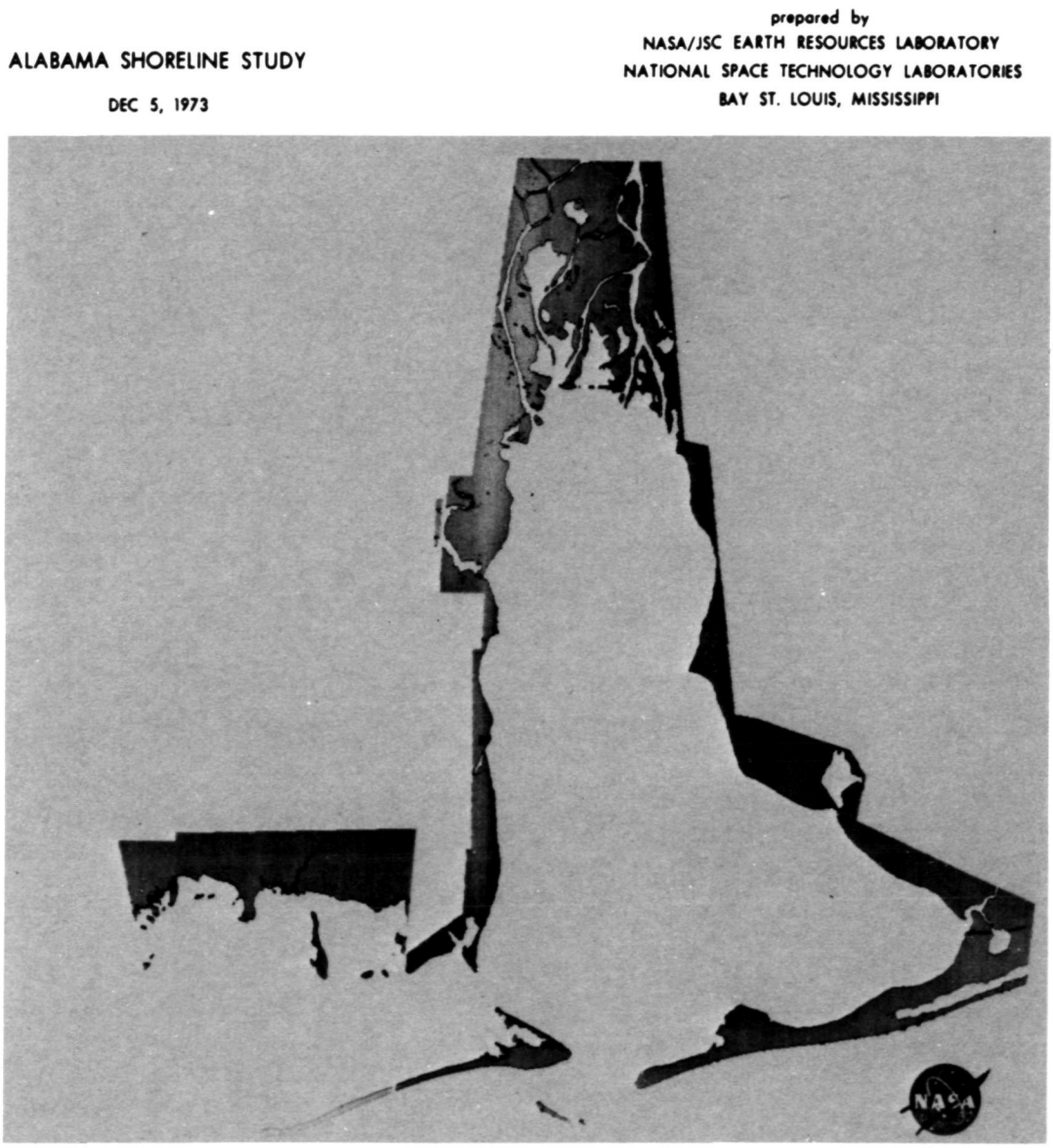


Figure 7.- Tidal shoreline measurement using LANDSAT data from 1973 was 879 km.

THE MAPPING OF MARSH VEGETATION USING AIRCRAFT MULTISPECTRAL SCANNER DATA M-14

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ABSTRACT

A test was conducted to determine if salinity regimes in coastal marshland could be mapped and monitored by the identification and classification of marsh vegetative species from aircraft multispectral scanner data. The data was acquired at 6.1 km (20,000 ft.) on October 2, 1974, over a test area in the coastal marshland of southern Louisiana including fresh, intermediate, brackish and saline zones. The data was classified by vegetational species using a supervised, spectral pattern recognition procedure. Accuracies of training sites ranged from 67% to 96%. Marsh zones based on free soil water salinity were determined from the species classification to demonstrate a practical use for mapping marsh vegetation.

INTRODUCTION

The United States can claim 30 million acres of marsh, or non-forested wetland, among its 26 coastal states and territories (1). The marsh includes such aquatic areas as fresh water lagoons and sloughs, estuaries, and the generally more saline coastal interfaces.

The coastal zone not only offers residence to approximately one-third of the nation's population, but also contains vast marshlands which represent an economically valuable, renewable resource. Non-forested wetland provides breeding grounds for commercial fish, shellfish, and fur-bearing animals. It also provides recreational activities such as boating, hunting and fishing, and represents a natural purification and drainage system for water flowing to the coast from more congested areas. Any environmental change within the marsh may impact the benefits derived from it, and thus monitoring the marsh becomes necessary for proper management.

One method of monitoring the marsh is the recording of marsh vegetation, as any type of vegetation growing in an area is an indicator of its environment. This paper deals with the utilization of multispectral remote-sensing by the modular multiband scanner (MMS) as a means of mapping expanses of marsh vegetation for use in the environmental monitoring of salinity intrusion.

Description of Study Area

A 72.5 km transect through the marsh of Louisiana, which alone claims seven million acres of marsh, was selected for the study described in this paper (Fig. 1). The study area is a representative sample of the Louisiana marshes, which originated from the old delta of the Mississippi River as it shifted course with time along the coast. The area is of interest because it is believed to be undergoing salt water penetration from the coast due to the introduction of man-made canals (2). Further, the same area is experiencing a reduction of fresh water flow from the Mississippi River and its tributaries due to the imposition of levee systems that prevent natural flooding of the marsh (3).

Changes in salinity levels give rise to environmental change, affecting marine productivity. The Louisiana marsh serves as a nursery for such commercially valuable animal life as menhaden, crab, oyster, shrimp, nutria, mink and muskrat, each depending on the status quo of a given salinity range to survive, where the brackish marsh, between fresh and salt water regimes, is the most productive (1). The study area includes a transitional zone of brackish marsh, grading into fresher inland marsh in one direction and more saline coastal marsh in the other.

In a more general sense, the study area may be representative of most marshes, because though geographically dispersed across the continent, the marsh maintains a uniformity in type and succession from Nova Scotia to Mexico, where water is the common factor and sodium chloride is the limiter (4). Thus, such uniformity of marsh suggests a general applicability of the results of this localized study to other areas.

Concept

The establishment of particular vegetative species in the marsh is dependent on such environmental factors as tidal phenomena, soil type, rainfall, temperature, and both horizontal and vertical gradients of soil salinity (5).

Comprehensive studies of the Louisiana coastal marsh vegetation have arranged dominant marsh species into groups based on soil water salinity alone (2, 6). Typical marsh types are shown in Figs. 2-23. The most recent work, premised on the salinity groups mentioned above, has divided the Louisiana marsh into four types: fresh, intermediate, brackish, and saline, each type being characterized by a given soil salinity range and association of plant species (Tab I) (7). Chabreck's 1968 marsh zonation of Louisiana, the work mentioned above, was accomplished by the recording of vegetation types from a helicopter following transect lines approximately 12 km (7.5' in latitude) apart, with interpolation of the salinity zones between the lines (Fig. 24).

The objective of this paper is to demonstrate that the same task of identification of marsh vegetation and the determination of marsh salinity zones can be accomplished by an aircraft multispectral remote-sensor with the advantages of greater efficiency and the accuracy associated with total area coverage. This investigation is preliminary to the classification of satellite multispectral data for marsh salinity zone determination.

EXPERIMENT DESIGN

The area described in this paper represents flight line #3 of the 15 flight-line design set of NASA Mission 287, from which MMS data and color IR imagery were acquired in the Louisiana marsh on October 2, 1974. Associated information for flight line #3 follows:

Aircraft	Ground Speed	Altitude	Time (CST)		Sensors	Scan Rate
NP3A	6.5 km/hr	6.1 km	Start	11:20:00	Zeiss	
			Stop	11:26:00	MMS[1]	12 rev./sec.

[1]The MMS has an instantaneous field of view of 2.5 milliradians, a full scan angle of $100^{o} \pm 20^{o}$ and a scan rate range of 10-100 revolutions/sec.

Possible training sites, for use in the supervised pattern recognition system of classification, were selected from color IR imagery acquired over the area in 1973, based on variations in texture and color that would lead to sites representative of dominant marsh vegetative species. Expanded chronopaques of the color IR imagery were produced on which the training sites were marked to use as "maps" for the ground truth expedition.

Ground truth of the training sites was accomplished almost exclusively by helicopter July-August 1974, since the marsh was generally inaccessible by car and often even by boat. While the helicopter hovered over a training site located on the chronopaque map, several overhead photographs were taken between 61m to 15m (200' to 50') and observations were recorded regarding the % barren and/or water in the site and the total % vegetation in the site. The percent of each observed species and dead plant material was also noted. Species not immediately identifiable were collected for laboratory study and herbarium mounts.

The field description of each training site was reviewed and the training site rejected for further use in the classification process if it did not represent a dominant marsh species or typical association of species.

The original pulse-code-modulated tape which recorded the MMS Mission 287 data was decommutated and made computer-compatible on the data analysis station (DAS) at the Earth Resources Laboratory at the National Space Technology Laboratory, Bay St. Louis, Mississippi. MMS channels 5, 7, 8 and 10, representing wavelengths .58-.62, .66-.70, .70-.74 and .97-1.06 μm, respectively, were used in the pattern recognition classification (8). Salinity zones were interpreted from the resultant marsh vegetational classification and compared with those derived by Chabreck (7).

RESULTS

The observed composition of each training site used in the classification of the study area is listed in Table II. Usually, one species dominated a training site, with one or more subdominant species occurring in association with the dominant. Some sites included a given percentage of water and/or sediment. The locations of training sites are indicated on the color IR imagery acquired from NASA Mission 287 (Fig. 25).

The marsh vegetation of the study area was classified from the MMS data using water and six different vegetative classes (Fig. 26). The unclassified areas probably represent agricultural fields, barren, and/or urban areas for which no training sites were included. Only the area covered by 90° of the total 120° scan is shown in the classified map.

Classification accuracies of the training sites, a function of class versus class-name percent occurrences, ranged from 68.7% to 96.0%, with an average of 88.2% (Table III).

Salinity zone lines within the study area were defined associations where *Sagittaria falcata*, *Panicum hemitomon*, and *Myrica cerifera* as dominants indicated a fresh zone; *Spartina patens* as a dominant indicated a brackish zone; *Spartina alterniflora* and *Avicennia nitida* as dominants indicated a saline zone; and the transitional area where *Spartina patens* appeared with other fresh marsh vegetative types indicated an intermediate zone (Fig. 27b). The salinity zone delineation derived from this remotely-sensed classification differed from the delineation derived by line-transect method in 1968 (Fig. 27a). The latter indicated a broader area of intermediate zone, but not extending as far south as in the former, and a larger area of saline zone extending more inland.

DISCUSSION

A September-October time frame for data acquisition was chosen based on the fact that the majority of marsh species are mature at that time, many of them flowering in the fall (6). The multispectral signatures of mature plants were assumed they would be more distinct, producing better separation and less misclassification, although this point may not be true in certain cases. Since the data was collected in a north-south direction, a flight time when the sun would be directly overhead was stipulated to minimize the illumination of one side of the flight line more than the other. Ground truth field work for identification of training site vegetation was timed to coincide, at least in the same season, with MMS data acquisition to avoid misrepresentation of training site location and vegetative type input to the pattern recognition system.

Analysis of the processed data led to some interesting observations. At an altitude of 6.1 km, the MMS instantaneous field of view (resolution cell size) is 15 m. Training sites large enough to include at least 25 resolution cells were considered statistically significant samples. Standard deviations of the mean reflected radiation in each channel for a given

training site seem to be indirectly proportional to resolution cell size, the multispectral response of a site becoming less integrated and the responses of different elements within a site more discrete with lower altitude and consequent greater resolution, based on this author's experience of MMS data from 3.05 km.

Of a possible 11 channels with a wavelength range of .38 μm to 14 μm, only channels 2, 5, 7, 8, 9 and 10 were able to be decommutated from the original MMS tape. Analysis of the obtained channels indicated that the recorded reflected radiation was not a function of ground elements alone. As the scan angle increased from nadir, so did reflected radiation due to the atmospheric interference associated with longer path length. Data from the shorter wavelength channel 2, .44-.49 μm, seemed most affected by the greater amount of light scattering related to the atmosphere. Therefore, channel 2 data was dropped and the combined signal of channels 5, 7, 8 and 10 improved. Homogeneous training sites were desired, but in an extensive area of uncultivated vegetation, one or more species may grow naturally in association with another. Thus, the multispectral signature of a training site may represent in some cases the integrated response of a mixture. The question of the degree to which a mixture may vary in composition and still be represented by the same signature needs to be addressed, as it probably affected the classification accuracy of this investigation. Similarly, the amount of water tolerated in a marsh training site without producing an unacceptably high standard deviation of the mean reflectivity for a given channel should be studied as it relates to this classification.

In comparing color IR imagery to classified scanner data, more marsh vegetative types could be identified by the MMS data (Fig. 26) than by photo-interpretation of color IR imagery (Fig. 25). The relatively high accuracies of the training site classifications, except for that of the *Spartina patens/Cyperus* spp. which probably was affected by the presence of water, indicated good separation of the vegetative classes.

Once the remotely-sensed identification of vegetation in the marsh study area was accomplished, delineation of the area into salinity zones depended on definition alone. Chabreck's similar delineation of salinity zones of the same area (Fig. 27a) is the only basis for comparison with the results of this investigation. However, the variable introduced by the two different methods of data acquisition and salinity zone interpretation does not make the comparison direct. Nevertheless, the salinity zones determined by this investigation follow the same trend as those determined by the work mentioned above. Variations between the 1968 determination and the one represented by this investigation may be explained by the natural phenomena of salinity intrusion, fluctuations in rainfall and spring floods that have occurred since the earlier work.

CONCLUSION

Results of this investigation demonstrate that vegetational species can be identified and mapped with a good degree of accuracy over a large area of the Louisiana marsh by using aircraft multispectral scanner data. The same technique can probably be applied to mapping marsh vegetation in other areas, as well.

This capability can be applied to determine salinity zones within the marsh for monitoring salinity intrusion, a factor influencing the growth and ultimate harvesting of fish, shellfish, and fur-bearing animals for commercial use.

Further, the remote-sensing capability of marsh species identification can be applied to monitor the distribution of one or more plant species as it may affect: (1) navigation, as in the case with the water hyacinth, (2) marine productivity estimates, as in the case with oystergrass, (3) wild life foraging, as in the case with 3-cornered grass, and (4) coastal zone definition.

ACKNOWLEDGEMENTS

I wish to acknowledge the effort of the Lockheed Electronics Co., Inc., personnel who supported this investigation, particularly those of Chris Gauthier, Wildlife Specialist, and Ron Vaughn, Data Processor. I also wish to extend special thanks to Ronnie Pearson, NASA/ERL mathematician, for his work with atmospheric interference, and Howard Clark, General Electric, for the botanical expertise he contributed to this study.

REFERENCES

1. Louisiana Advisory Comm. on Coastal and Marine Resources. Sept., 1973. Louisiana Wetlands Prospectus.

2. NASA Earth Resources Laboratory. Dec. 20, 1973. ERTS-B proposal, Vegetation Mapping and Measurement of Land/Water Percentage and Interface Length for Marsh Classification and Monitoring of Salinity Intrusion and Erosion in Louisiana. Johnson Space Center.

3. O'Neil, Ted. 1949. The Muskrat in the La. Coastal Marshes. La. Wildlife and Fisheries Comm., New Orleans. 159 p.

4. Allan, P. F. 1950. Ecological Bases for Land Use Planning in Gulf Coast Marshes. J. Soil Water Conser., 5(2), 57-62.

5. Chapman, V. J. 1960. Salt marshes and salt deserts of the world. Interscience. NY 392 p.

6. Penfound, Wm. T and Hathaway, Edward S. 1938. Plant Communities in the Marshlands of S.E. La. Ecological Monographs, V. 8, No. 1.

7. Chabreck, R. H. 1972. Vegetation, Water and Soil Characteristics of the La. Coastal Region. La. State University and Ag. and Mechanical College. Bull No. 664.

8. Whitley, Sidney L. Jan., 1975. A procedure for automated land use mapping using remotely sensed multispectral scanner data. NASA TR R-434. Johnson Space Center.

TABLE I. MARSH SPECIES ASSOCIATION FOR

SALINITY ZONE DEFINITIONS

[from Ref 7]

MARSH ZONE	FREE SOIL WATER SALINITY AVE. (PPT)	MAJOR INDICATOR SPECIES
Fresh	1	MAIDEN CANE *(Panicum hemitomon)*, *Hydrocotyl sp.*, WATER HYACINTH *(Eichornia crassipes)*, PICKEREL WEED, *(Pontederia cordata)*, ALLIGATOR WEED, *(Alternanthera philoxeroides)*, BULLTONGUE *(Sagittaria sp.)*
Intermediate	3.3	WIREGRASS, *(Spartina patens)*, DEER PEA *(Vigna repens)*, BULL TONGUE WILD MILLET *(Echinochloa walteri)*, BULLWHIP *(Scirpus californicus)*, SAWGRASS *(Cladium jamaicense)*
Brackish	8.1	WIREGRASS, THREE CORNERED GRASS *(Scirpus olneyi)*, COCO *(Scirpus robustus)*, WIDGEONGRASS *(Ruppia maritima)*
Saline	15.9	OYSTERGRASS *(Spartina alterniflora)*, *Salicornia sp.*, BLACK RUSH, *(Juncus roemerianus)*, *Batis maritima*, BLACK MANGROVE *Avicennia nitida*, SALTGRASS *(Distichlis spicata)*

TABLE II. COMPOSITION OF TRAINING SITES FOR LINE 3-2, MISSION 287[a]

Training Site Field Number	Composition
3	*Sagittaria falcata* 40%, *Panicum hemitomon* 40%, *Typha sp.* 5%, *Eleocharis microcarpa* 5%
5	*Spartina patens* 70%, *Cyperus sp.* 10%, *Bacopa monnieri* 5%, water 15%
9	*Myrica cerifera* 40% *Panicum hemitomon* 50%
11	*Spartina patens* 50%, water and sediment 50%
75	*Spartina alterniflora* 80%, water and sediment 20%
78	*Avicennia nitida* 70%, *Spartina alterniflora* 15%, Water 10%
178	*Spartina patens* 95%, *Scirpus sp.* 3%
179	*Spartina patens* 90%. water 10%
198, 200-209	water (varying depths and turbidity)

[a/] determined by field observations July-Aug. 1974

TABLE III. ACCURACY CHECK OF TRAINING SITES FOR MARSH CLASSIFICATION OF FLIGHT LINE 3-2, MX. 287

		CLASS-NAME % OCCURRENCES								
CLASS	1 3SFPA	2 11SP	3 178SP	4 9MCPA	5 5SPCY	6 H_2O	7 179SP	8 75SA	9 78ANSA	27 UNCLASS.
1.- 3SFPA	91.67	2.63		.44					.22	5.04
2 - 11SP	2.63	89.25	1.97	1.10					1.10	3.95
3 - 178SP		2.80	89.32		.53		1.23			6.13
4 - 9MCPA	.51	.25		95.96						3.28
5 - 5SPCY	.29	2.30	1.01		68.68	3.16	.14			24.43
6 H_2O						95.25		.56		4.19
7 - 179SP	.26						76.30		.26	23.18
8 - 75SA					.16	.49	1.79	92.67		4.89
9 78ANSA		1.79							94.64	3.57

SFPA = *Sagittaria falcata/Panicum hemitomon*
SP = *Spartina patens*
MCPA = *Myrica cerifera/Panicum hemitomon*
SPCY = *Spartina patens/Cyperus sp.*

H_2O = WATER
SA = *Spartina alterniflora*
ANSA = *Avicennia nitida/Spartina alterniflora*

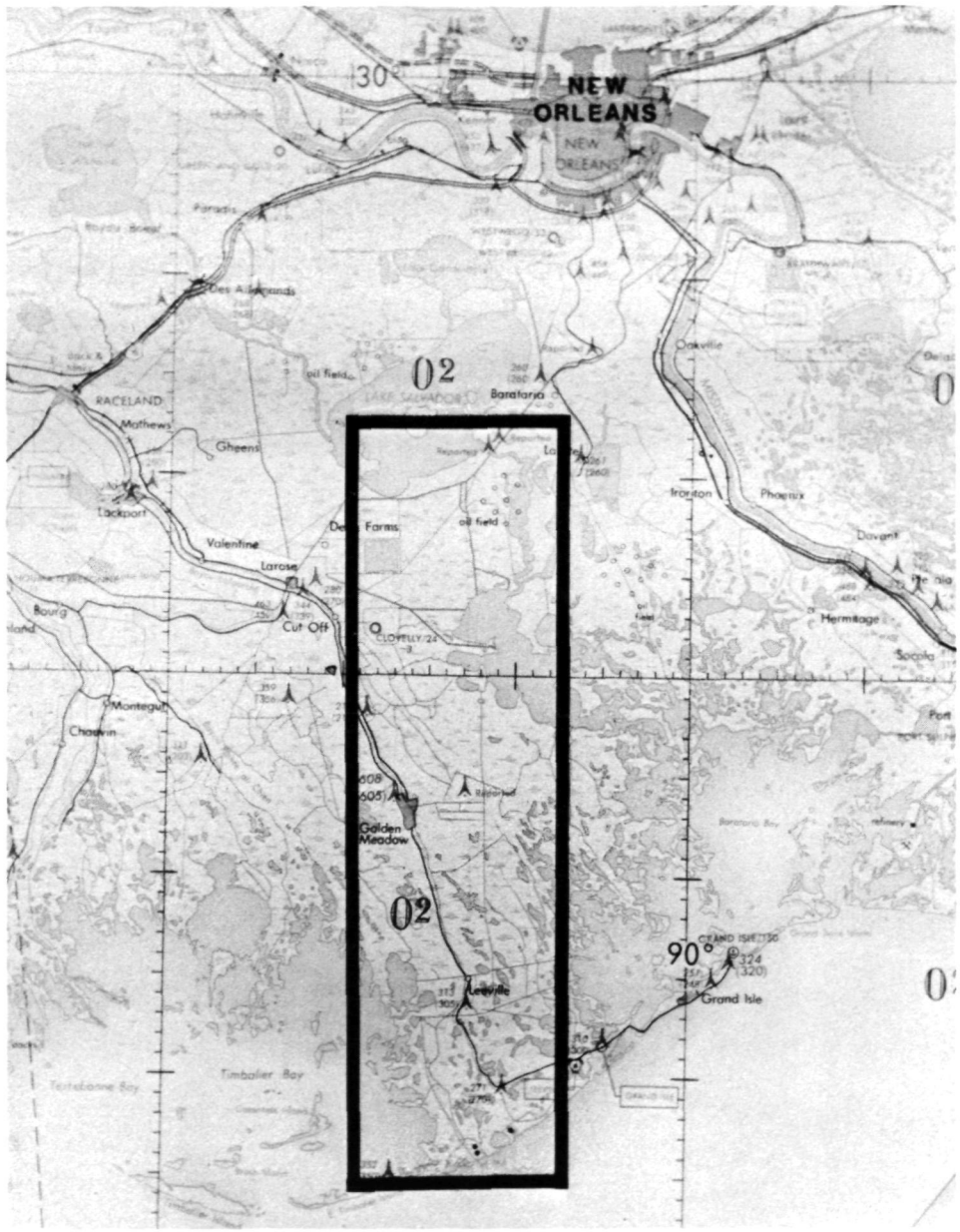


Fig. 1 Test site location MMS mission 287
flight line 3-2, Oct 2, 1974



Fig. 2 Black willow, Salix nigra, commonly borders fresh marsh areas along spoil banks and newly accreted land.



Fig. 3 The interface between fresh marsh (left), and cypress swamp (right) indicates an ecotone. Dead standing trees in the marsh represent a changing environment



Fig. 4 Bulltongue, Sagittaria falcata, is a common fresh marsh plant.



Fig. 5 Low shrubs (background) commonly border spoil banks, giving way to fresh marsh plants such as bulltongue (foreground).



Fig. 6 Helicopter view of bulltongue indicates standing water is a common element of fresh marsh.



Fig. 7 Cat - tail, Typha latifolia, is a typical marsh species.

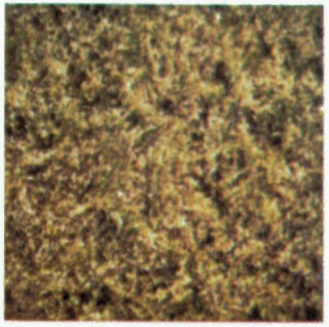


Fig. 8 Helicopter view of maidencane, Panicum hemitomon, dominating the Louisiana fresh marsh.



Fig. 10 Water hyacinth, Eichhornia crassipes, forms floating vegetative mats in the fresh marsh.



Fig. 9 Helicopter view shows water hyacinth choking waterways bordered by buckbrush, Baccharis halimifolia, a fresh to brackish shrub.



Fig. 11 Roseau cane, Phragmites communis, is a 2-1/2 to 4 m grass usually found along elevated areas in the fresh marsh.



Fig. 12 Standing roseau cane stalks from the previous growing season are shown at the back slope of a spoil bank, indicated by the growth of wax myrtle, Myrica cerifera, in the fresh marsh.

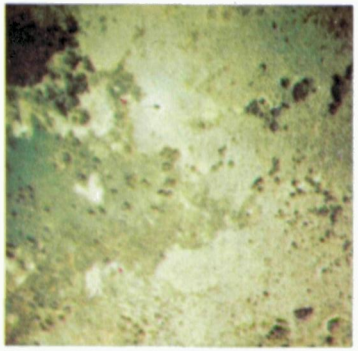


Fig. 13 Helicopter view at 155m shows variation in color and texture pattern produced by the association of buckbrush and roseau cane in the fresh marsh.



Fig. 14 Helicopter view at 30 m showing dioecious nature of buckbrush where the lighter colored plant is in flower.



Fig. 15 An association of wiregrass, Spartina patens, (foreground) three - cornered grass, Scirpus olneyi, and blackrush, Juncus roemerianus, indicates a brackish marsh.

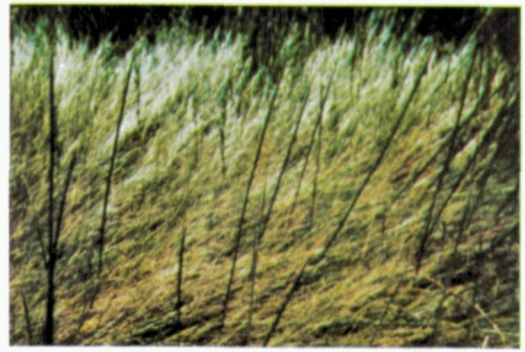


Fig. 16 A mixture of wiregrass and three - cornered grass: wiregrass dominates this area with dispersed areas of three - cornered grass.



Fig. 17 Helicopter view at 15 m shows homogenous stand of wiregrass.



Fig. 18 Oyster grass, Spartina alterniflora, is a 1-2 m grass dominating the saline marsh.

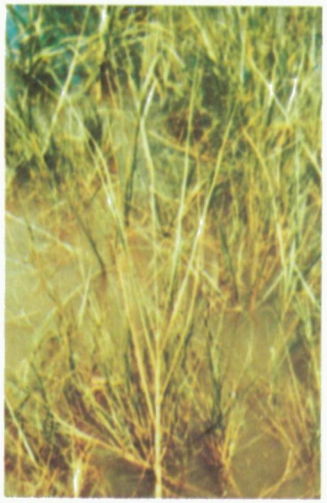


Fig. 19 Salt grass, Distichlis spicata, a plant 15 to 50 cm, commonly grows in association with the taller oyster grass.

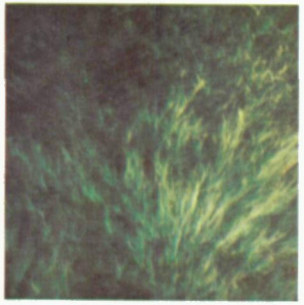


Fig. 20 Helicopter view of homogenous stand of flowering oyster grass found in the saline marsh.

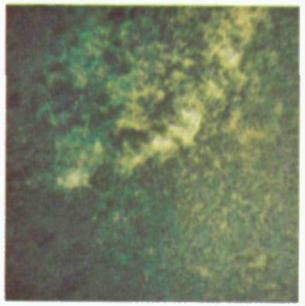


Fig. 21 A mixture of salt grass (foreground), oyster grass (light green area) and wiregrass, is a common saline type association as viewed from 60 m.



Fig. 22 Extensive blackrush occurs in a brackish to saline area, interfacing an oak-pine chenier background.



Fig. 23 Helicopter view of black mangrove, Avicennia nitida, a 1-2 m shrub growing along the most saline areas of the Louisiana coast.

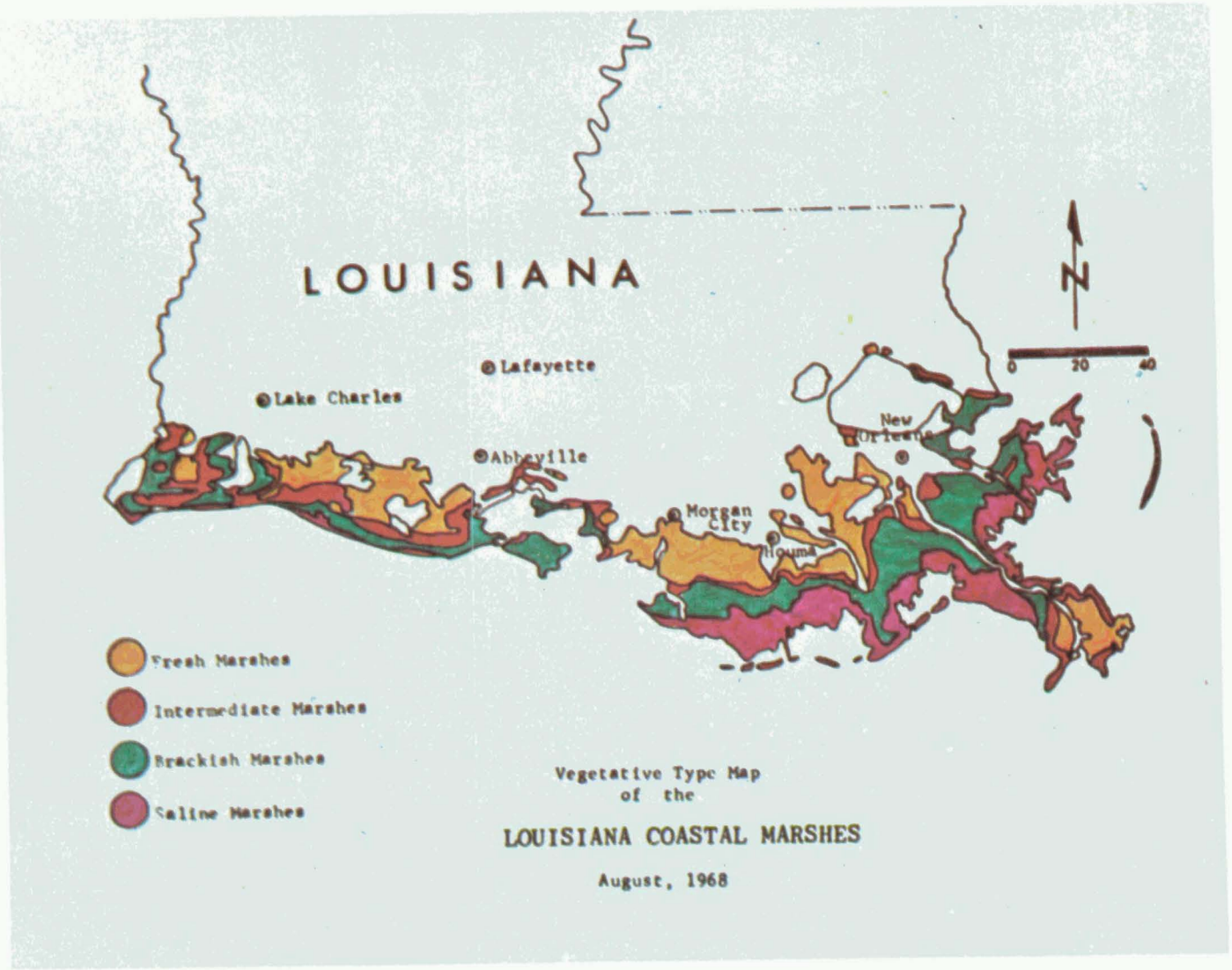

LOUISIANA
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0
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Lafayette
Lake Charles
Abbeville
New Orleans
Morgan City
Houma
Fresh Marshes
Intermediate Marshes
Brackish Marshes
Saline Marshes
Vegetative Type Map
of the
LOUISIANA COASTAL MARSHES
August, 1968

Fig. 24

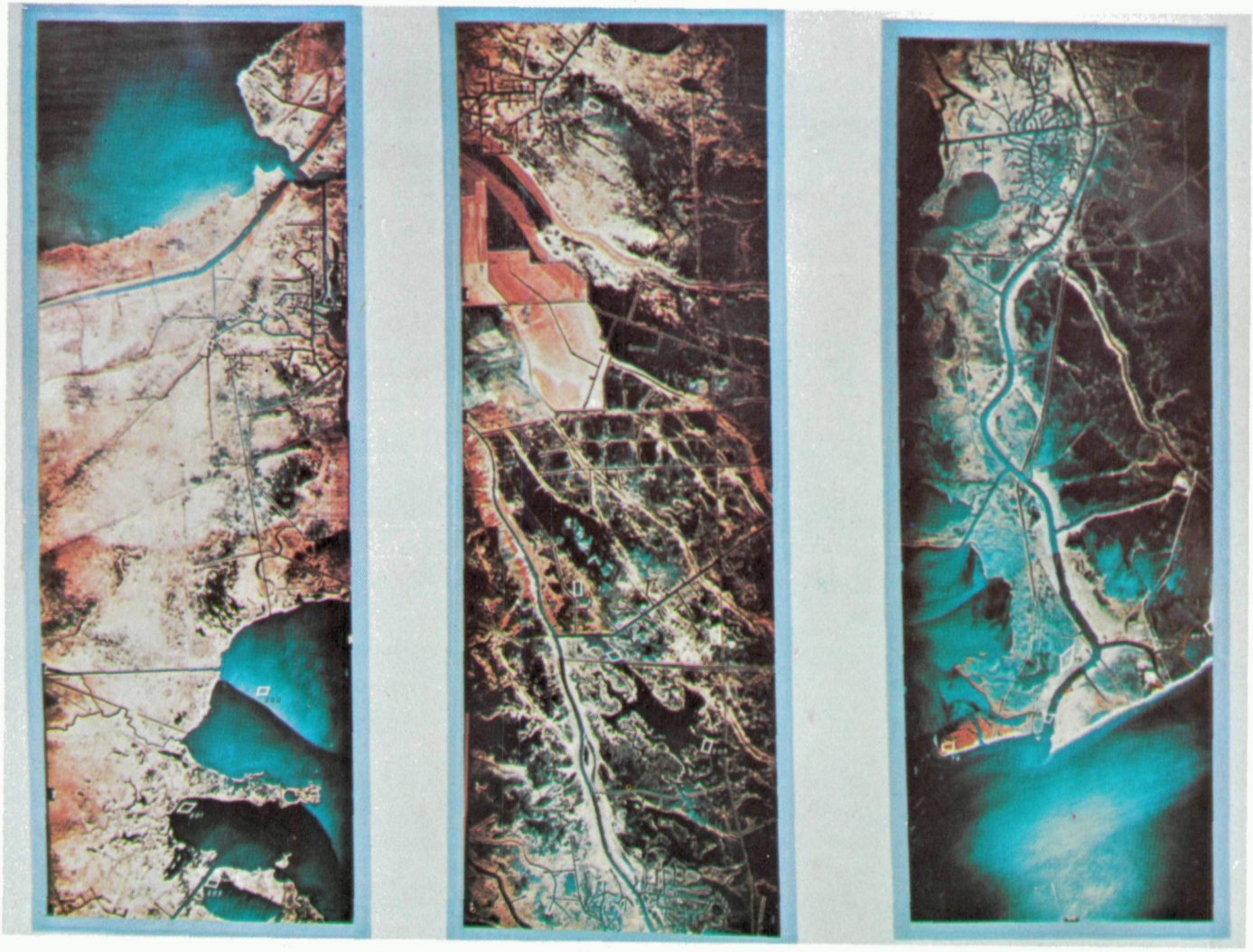


Fig. 25 Training site locations on color IR photography of south Louisiana marsh flight line 3, MX 287.

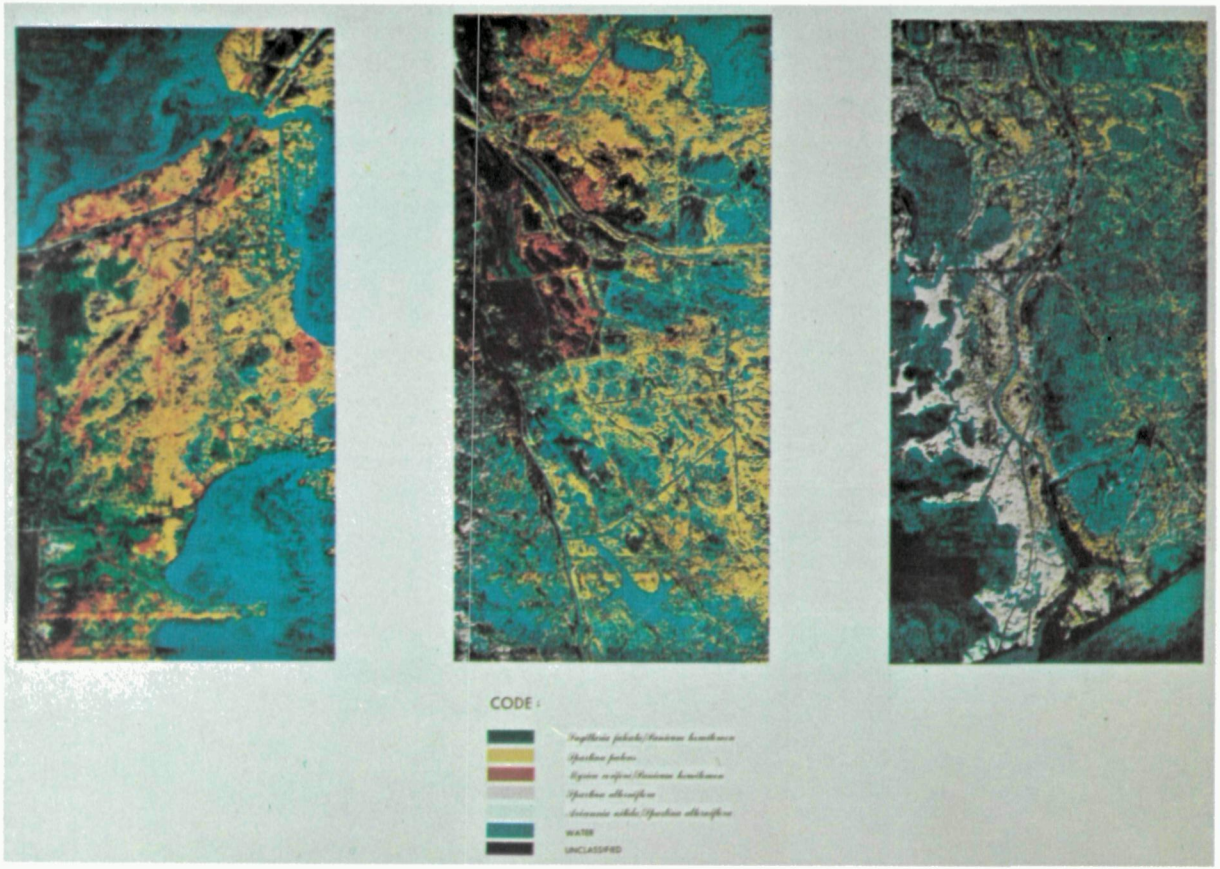


Fig. 26 MMS classification of major species associations of marsh vegetation Oct 2, 1974.

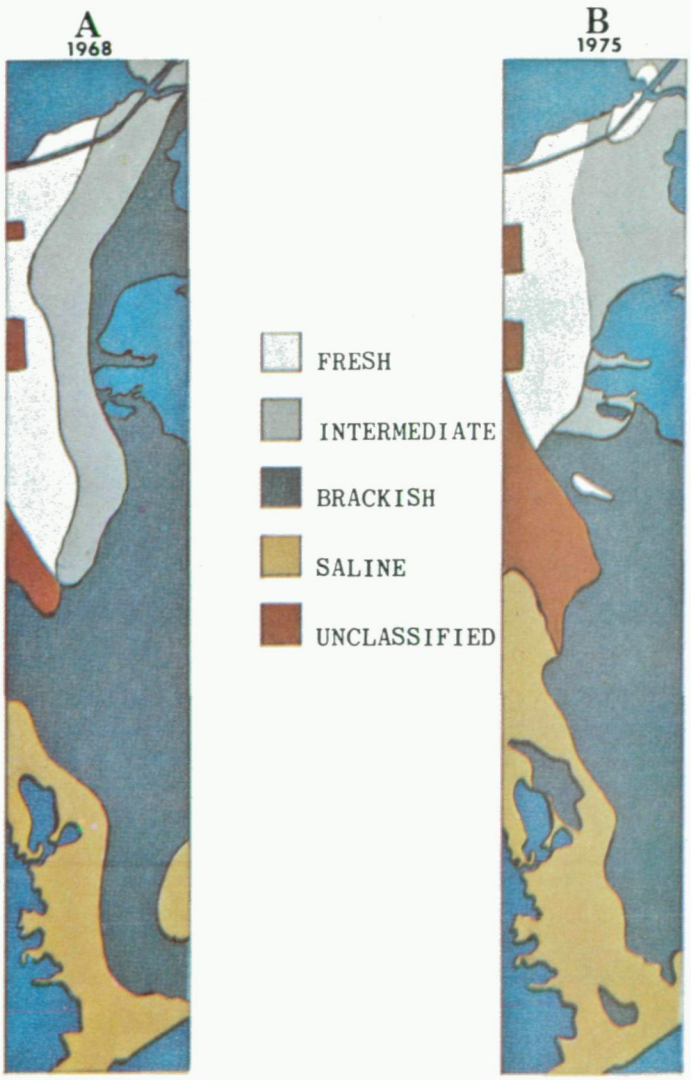


Fig. 27 Thematic maps of marsh salinity zones

A Marsh zones determined by line-transect method (R.H. Chabreck)

B Marsh zones determined from multispectral scanner data 20'K

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